

**Tire-Derived Rubber
Flooring Chemical
Emissions Study:
Laboratory Study Report**



California Department of Resources Recycling and Recovery

October 2010

Contractor's Report
Produced Under Contract By:
Public Health Institute
555 12th Street, 10th Floor
Oakland, California 94067

S T A T E O F C A L I F O R N I A

Jerry Brown
Governor

John Laird
Secretary, California Natural Resources Agency

Department of Resources Recycling and Recovery

Mark Leary
Acting Director

Department of Resources Recycling and Recovery
Public Affairs Office
801 K Street (MS 17-15)
P.O. Box 4025
Sacramento, CA 95812-4025
www.calrecycle.ca.gov/Publications/
1-800-RECYCLE (California only) or (916) 341-6300

Publication # DRRR-2011-002



To conserve resources and reduce waste, CalRecycle reports are produced in electronic format only. If printing copies of this document, please consider use of recycled paper containing 100 percent postconsumer fiber and, where possible, please print images on both sides of the paper.

Copyright © 2011 by the California Department of Resources Recycling and Recovery (CalRecycle). All rights reserved. This publication, or parts thereof, may not be reproduced in any form without permission.

Prepared as part of contract number IWM 03082 for \$100,000.

The California Department of Resources Recycling and Recovery (CalRecycle) does not discriminate on the basis of disability in access to its programs. CalRecycle publications are available in accessible formats upon request by calling the Public Affairs Office at (916) 341-6300. Persons with hearing impairments can reach CalRecycle through the California Relay Service, 1-800-735-2929.

Disclaimer: This report was produced under contract by the *Public Health Institute*. The statements and conclusions contained in this report are those of the contractor and not necessarily those of the Department of Resources Recycling and Recovery (CalRecycle), its employees, or the State of California and should not be cited or quoted as official Department policy or direction.

The state makes no warranty, expressed or implied, and assumes no liability for the information contained in the succeeding text. Any mention of commercial products or processes shall not be construed as an endorsement of such products or processes.

Table of Contents

Executive Summary	v
Preface	vii
Acknowledgments.....	viii
Introduction.....	1
Goals of This Study	1
Tire Production, Tire Waste, and Tire-Derived Rubber Products	2
Environmental and Health Risks	5
Methodology	7
Flooring Product Acquisition	7
Specimen Emission Testing	8
Laboratory Analytical Methods.....	9
Data Analysis	11
Chamber Size/Flow Rate Comparison	14
Results and Analyses	15
Products Tested	15
Microscopic Visualization of TDR Flooring Products.....	18
Laboratory Data Quality.....	19
Emission Factors	21
Exposure Scenarios and Modeled Room Concentrations.....	34
Discussion	38
Unresolved Chemical Compounds	38
Comparison of Emissions from Products Across Production Lots	39
VOC Release of TDR Flooring in Longer Periods.....	43
Exposures to Chemicals of Concerns	48
Comparison of Emissions of Current Study with BMES	49
Summary and Recommendations.....	51
Abbreviations and Acronyms	54
References and Bibliography	55
Appendix A. Correspondences to Rubber Flooring Manufacturers.....	A-1
Appendix B. Protocols for Material Emission Testing	B-1
Appendix C. Microscopic Images of Products Tested in Study	C-1
Appendix D. Laboratory Data for Products Tested in Study	D-1
Appendix E. Indoor Air Reference Exposure Levels (iRELs).....	E-1

List of Tables

Table 1	Chemical compounds associated with tire production.....	3
Table 2	California waste tires disposal in 2006 (Millions of Passenger Tire Equivalents).	3
Table 3	Emission test chambers for specimen conditioning and sampling.....	9
Table 4	Exposure scenarios with parameters used to calculate room concentrations.....	13
Table 5	Characteristics of rubber flooring product (n=25) tested in study.	16
Table 6	Description of rubber flooring products tested in study, grouped by rubber-type and primary use.	17
Table 7	Relative standard deviation (RSD) of 14-day emission measurements	20
Table 8	Maximum chemical emission factors found in flooring specimens (in five or more).	22
Table 9	Maximum emission factors for chemicals found in only four or less flooring specimens.	23
Table 10	Maximum emission factors for chemicals classes (i.e., compounds not fully identified)	24
Table 11	Total emission factors at 14 days from flooring samples: Semi-identified and Unidentified VOCs.	33
Table 12	Modeled room concentrations for four exposure scenarios – maximum case for Tire-derived rubber (TDR) <i>Interior-use</i> products.....	35
Table 13	Modeled room concentrations for four exposure scenarios – maximum case for TDR <i>Exterior-use</i> products.....	36
Table 14	Modeled room concentrations for four exposure scenarios – maximum case for New Rubber (NR) <i>Interior-use</i> products.....	37
Table 15	Comparison of results for two samples using Tenax and Canister collection.	39
Table 16	Selected chemical emission factors at 14 days for specimens for five sets of samples from multiple production lots.	42
Table 17	Emission factors for selected chemicals from rubber flooring products for 14-d and longer testing periods.	44
Table 18	Comparison of emissions for selected chemicals from various flooring products tested in the Current Study and BMES.	49

List of Figures

Figure 1	Emission test chambers used in the study.....	8
Figure 2	Duplicate chamber and Tenax cartridge tube (TCT) set-up.....	11
Figure 3	Photos showing cross-sectional views of rubber flooring (a) homogeneous (ID 3.2) and (b) layered composition (ID 5.1).	15
Figure 4	Images of embedded fibers in flooring materials (40x magnification).....	18
Figure 5.	Top and bottom views of flooring products: (a) homogeneous and (b) layered composition (40x magnification).....	19
Figure 6	Emissions of major compounds for 14-day replicate measurements.....	20
Figure 7	Emission factors at 14 days for samples by type: Benzothiazole, Methyl isobutyl ketone, and Cyclohexanone.....	27
Figure 8	Emission factors at 14 days for samples by type: Xylenes and Napthalene.	28
Figure 9	Emission factors at 14 days for samples by type: Butylated hydroxytoluene, Ethylbenzene, and Toluene.....	29
Figure 10	Emission factors at 14 days for samples by type: Acetaldehyde, Acetone, and Formaldehyde.	30
Figure 11	Emission factors at 14 days for samples by type: Benzene, Carbon disulfide, and Styrene.	31
Figure 12	Emission factors at 14 days for samples by type: Semi-identified and Unidentified VOCs (added to Identified).....	32
Figure 13	Emissions for two production lots of Product 2.1.Z.	40
Figure 14	Emissions for four production lots of Product 3.1.Z.....	40
Figure 15	Emissions for two production lots of Product 3.2.Z.	41
Figure 16	Emissions for two production lots of Product 6.3.Z.	41
Figure 17	Emissions for two production lots of Product 8.2.Z.	42
Figure 18	Chemical emission rates (SumVOC) at 28, 60, and 90 days for TDR (interior) flooring samples	45
Figure 19	Chemical emission rates (SumVOC) at 28, 60, and 90 days for TDR (exterior) and NR flooring samples.....	45
Figure 20	Comparison of emission factors for samples tested simultaneously in 56 L and 12 L chambers	47

This page intentionally left blank.

Executive Summary

Tire-derived rubber (TDR) flooring is a small, but growing, sector of the floor coverings market, and it provides a beneficial use for waste tires, as an alternative to disposal into landfills. In 2001, the California Department of Public Health (CDPH) completed its Building Material Emissions Study or BMES (published in 2003), which found TDR products to emit a substantial amount of chemicals with no established reference exposure levels for health protection, as well as a large number of small peaks of volatile organic compound (VOC) that could not be identified. The CDPH's earlier findings led the authors to conclude (in 2003) that... *"further refinement and testing of rubber-based...products are necessary before these products can be promoted for wide use in most indoor environments."* In addition, the emissions study raised questions about how long certain chemicals would off-gas from these products over time.

Study Goals: The current study examined volatile organic compound (VOC) emissions for a wider range of TDR flooring products. It aimed to provide information relevant to identify chronic exposure to VOCs emitted from products, as well as the decline of emissions over time. Exposure scenarios for a set of indoor conditions were used to predict potential exposures and health risks of TDR-flooring products for a range of indoor applications.

Methods: We acquired a variety of TDR and NR (new rubber) flooring products directly from manufacturers shortly after production, including replicate samples manufactured in different production lots. Specimens were tested using CDPH's Standard Practice 14-day test period (as in the BMES); testing of individual samples was continued for three months. The protocol included sample conditioning for 10 day, followed by VOC testing after four days to yield the "14-day" emission factors. The protocol was "extended" and VOC emission tests also were conducted at 28, 60, and 90 days. Except during emission testing, specimens remained in individual conditioning vessels. Air samples were analyzed using laboratory standard operating procedures to determine the chamber concentration of VOCs and carbonyl analytes (including aldehydes) during each test period. The chamber concentration data were used to calculate emission factors for individual analytes emitted from each specimen. We had limited success in identifying previously unresolved GC/MS peaks, although were able to resolve many compounds into chemical classes. Low-power optical microscopy was used to record surface characteristic of each product.

Results: Results show that TDR and new rubber (NR) flooring products still emit a myriad of VOC chemicals, and their release is not uniform among the different products. Most of the chemicals emitted in the tested products could be identified, and most of emissions were from three to five compounds. In general, rubber flooring products were found to emit a range of VOCs at different rates due to variations in material properties, and thickness. Several TDR flooring products emitted high rates of VOCs over the tested period, although chemicals of known health concern were at low levels or absence in most products. Xylene, butylated hydroxytoluene, ethylbenzene, toluene, formaldehyde, and acetaldehyde were found in a range of products. Benzene and carbon disulfide were above the health threshold in one or two samples. These latter contaminants appeared to be due to minor constituents in the manufacturing process, since they were found in one production lot and not another. For similar products acquired from different production lots (i.e., manufacturing dates), the major emission constituents were found to be consistent over time.

Three compounds (benzothiazole, methyl isobutyl ketone, and cyclohexanone) were emitted at substantial rates for both TDR and NR flooring products for most products. Other major chemicals measured frequently included: butylated hydroxytoluene (BHT), xylenes, and ethylbenzene. These compounds were 50 percent or more of the total VOCs quantified in most products (and >75 percent in half the products). Chronic Reference Exposure Levels (cREL) are not established for the former three compounds or BHT. However, indoor air modeling for common building types indicated potential exposures above the cREL for acetaldehyde, benzene, formaldehyde, naphthalene, toluene, and xylene, based on emission rates for some rubber flooring products. Also, total measured VOC emission factors for some NR *indoor* and TDR *exterior* products were sufficient to raise room concentrations up to 10,000 $\mu\text{g m}^{-3}$ as compared to <1000 $\mu\text{g m}^{-3}$ for majority of products (for the 14-day tests).

Emission factors of most measured chemicals appeared to decline over the 90-day testing period. This trend appeared to be chemical and/or product specific, with some chemicals off-gassing rapidly and others slowly in the same product. The different emission factors may be related to the physical composition of the product or to other factors. The chemical emission rates were generally lower at 90 days compared to at the earlier periods. Emissions of most *chemicals of concern* declined quickly and were substantially lower in the samples longer than 28 days.

Conclusions and Recommendations: As noted in the 2003 BMES, the current study results showed that both TDR and NR flooring products emit a myriad of VOCs. A minority of products released excessive amounts of chemicals. TDR flooring products designated for *interior-only* use are generally lower emitting; *exterior* products were frequently “super VOC emitters.” NR flooring products in this study emitted higher amounts of some chemicals than TDR products. Indoor modeling for these product emission rates indicated potential exposures near the cREL for acetaldehyde, benzene, formaldehyde, naphthalene, toluene, and xylene at 14 days. Potential exposures were generally not high among the *interior-only* products tested, and emission rates for most of these chemicals appear to decrease by the 28-day tests. Recommendations related to TDR flooring products based on this study are:

- a. Subject to VOC screening of specific products under CDPH Section 01350, TDR and NR flooring may be acceptable for indoor use, although products designated for *exterior* or *exterior-interior* use should generally be avoided (indoors).
- b. TDR and NR flooring can emit high levels of chemicals that do not have health-based guidelines or standards, and occasionally, some major constituents are not readily identifiable by routine analytical methods. Because of these characteristics, consideration should be given to setting an allowable limit for “total” VOC emissions for rubber flooring (both TDR and NR) to be used indoors (e.g., as used in *Greenguard* IAQ certifications), as a supplement to CDPH Section 01350 VOC screening and acceptance criteria.
- c. Ample pre-occupancy *flush out* (or off-site pre-conditioning) is appropriate when TDR and NR flooring products are used indoors. Data for the current study suggest that most chemicals emissions are substantially reduced after ~28 days; however, substantial emissions of several compounds remained through the 90-day conditioning period. This raises concerns about “new” rubber flooring products impacts (e.g., sensory) persisting past installation.
- d. The inconsistent presence of a few chemicals (e.g., benzene) suggests occasional reliability problems for crumb rubber or processing chemicals sources. Manufacturers should screen sources of rubber and solvents used in rubber-flooring manufacturing for contaminants that are not essential to production.

Preface

Development of markets and alternative uses for waste tires is a major effort for the Department of Resources Recycling and Recovery (CalRecycle)—formerly known as the California Integrated Waste Management Board (Board)—and has significant environmental benefits. In 2001, the Board sponsored the Building Material Emissions Study (published in 2003), which measured the chemicals off-gassing from flooring products made with recycled tires, among other products. The study found that indoor uses of tire-derived flooring had the potential to cause exposures to several chemicals of concern above state air toxics guidelines.

In 2004, the Board contracted with the California Office of Environmental Health Hazard Assessment (OEHHA) to better characterize the chemical emissions from rubber-based products. The current project to conduct additional emissions testing research was funded by an OEHHA subcontract to the Public Health Institute for \$100,000, funded as part of Board Contract Number IWM 03082. This final report is submitted in partial fulfillment of the contract requirements.

The project was conducted in 2005 and 2006 by the California Department of Public Health (CDPH), called the Department of Health Services at that time. The research was conducted by the Indoor Air Quality Section of the Department's Environmental Health Laboratory Branch at the Richmond campus. Substantial in-kind support for staff, equipment, and supplies was provided by CDPH.

Acknowledgments

We are sincerely grateful to each of the flooring manufacturers for their interest and generous assistance in this study, and to CalRecycle for supporting this work from the California Tire Fund.

The authors thank the following individuals:

- Our chemists, Weldon Hall and Robert Miller, for their enormous efforts in coordinating and conducting the hundreds of emission tests and chemical analyses for this study.
- Our research assistants, Paola Taranta and Ryan Johnson, for their diligence and machinations in acquiring samples and information from flooring manufacturers.
- CDHS-IAQ staff, Dr. Janet Macher, Dr. Kunning Zhu, and Dr. Toni Stein, for their help on data analyses and preparation of this report (and the occasional hand in the laboratory), and Dr. Jeff Wagner, for guidance on microscopic imaging of the flooring samples.
- The following individuals for their advice, input, and review through the project:
 - Anthony Bernheim, AECOM Design
 - Alfred T. Hodgson, Berkeley Analytical Associates
 - Richard Lam, Office of Environmental Health Hazard Assessment
 - Hal Levin, Building Ecology Research Group
 - Dana Papke, CalRecycle
 - Linda Dickinson, CalRecycle
- Dr. Amy Arcus, contract manager, and Dr. Robert Blaisdell at the Office of Environmental Health Hazard Assessment for their advice, encouragement, and patience throughout this study.
- Gregory Dick, Brian Helmowski, William Orr, and Dana Papke at CalRecycle for their encouragement, direction, and patience.
- Judith Lubina, Carol Alliger, and Mike Peters, Public Health Institute, for their assistance and helpfulness in administrative matters

Report Authors

Jed M. Waldman, Ph.D., principal investigator
Kunning Zhu, Ph.D. and Robert Miller

Indoor Air Quality Section (Environmental Health Laboratory Branch)
Division of Environmental and Occupational Disease Control
California Department of Public Health

Introduction

Chemical emissions from common building materials may cause health risks, especially for those products that have a large rate of toxic chemical emissions and/or are present in large quantities in occupied settings. Volatile organic compounds (VOC) are of particular concern because they have characteristically high emission factors. Many VOCs are common to the manufacturing processes of building products. Among these are aromatic solvents (e.g., benzene and naphthalene), chlorinated hydrocarbons (e.g., carbon tetrachloride and trichloroethylene), non-chlorinated hydrocarbons (e.g., acrolein and butadiene), and carbonyl compounds used in resins (e.g., formaldehyde and acetaldehyde). Their ubiquity can lead to substantial chronic VOC exposures, as new products replace old ones over the lifetime of a building.

The Department of Resources Recycling and Recovery (CalRecycle)—formerly known as the California Integrated Waste Management Board (CIWMB)—sponsored the Building Material Emissions Study, or BMES (California Department of Health Services, 2003) to measure the chemicals off-gassing from building materials. The BMES included measurements of 77 separate materials in 11 different categories, with protocols developed for this broad scoping study. The emissions study tested 11 rubber flooring products, and identified a number of chemicals that were emitted by tire-derived rubber flooring products. Some of these chemicals appear on OEHHA's Reference Exposure Level lists, the Proposition 65 list, or the Toxic Air Contaminants (TAC) list. These lists establish toxic dose limits, but the latter does not establish exposure concentration limits. The emissions study also reported large amounts of other chemicals were emitted from some tire-derived rubber flooring products, but these chemicals could not be identified. The potential impact on indoor air quality of the myriad of constituents emitted led to the emission study's recommendation that rubber-based products not be promoted for wide use in most indoor environments until further studies are done.

Goals of This Study

The primary goal of this laboratory study was to identify and quantify volatile organic compound (VOCs) emissions from flooring made with recycled tire materials. Our focus was on tire-derived rubber (TDR) flooring products that are, or can be, used indoors. In an indoor setting, VOCs emitted from these products may result in chronic inhalation exposures or acute irritancy for occupants. For this study, we were principally concerned about emissions that may cause exposures to chemicals at levels of health concern.

Prior emissions testing in this laboratory relied on a standardized screening protocol used in the emissions study: a 10-day conditioning period followed by a four-day testing period, with reportage of emissions at 14 days. In order to ascertain VOC emissions over time for the current study, protocols were developed to extend the test period to 90 days. An additional goal was to repeat tests on the same products manufactured at different times to help characterize the variability in these products and the reliability of emission screening. Finally, the current study extended analytical limitations of the emissions study by attempting different techniques to analyze gas chromatograph/ mass spectrometer chemical peaks that were previously unidentified.

This laboratory study supported the California Office of Environmental Health Hazard Assessment (OEHHA) in their activities to better characterize the chemical emissions from rubber-based products, funded under an interagency agreement with the Board.

Tire Production, Tire Waste, and Tire-Derived Rubber Products

With more registered vehicles than any other state California has faced an increasing challenge in managing the millions of waste tires generated here each year. Under the *California Tire Recycling Act of 1989* (AB 1843), the state operates a waste tire management program, funded by fees on new tire purchases. The CalRecycle Tire Program budget in 2009-10 is \$34 million per year – a significant amount illustrating its importance. Its major elements include market development (50%), enforcement (18%), and cleanup (10%), and its primary goal is to divert tires from landfills and illegal dumping (CIWMB, 2009). Currently, of the 44 million waste tires generated in California annually (2006), ~75 percent were diverted, (CIWMB, 2007a).

Traditional disposal of waste tires (i.e., landfilling, combustion, and stockpiling) has been a major problem in the waste management (U.S. EPA, 1995). Stockpiled tires at a storage site in Westley, Calif., resulted in a serious fire hazard in 1999. Thereafter, Senate Bill 876 (Escutia, Statutes of 2000) was enacted to reduce the stockpiles of waste tire. Statewide efforts to convert the waste tires have been greatly increased. Currently, approximately three-quarters are reused, retreaded, recycled, burned, or other alternative uses, while the remaining (11 million) tires are disposed of in California's permitted solid waste landfills or stockpiled at permitted sites, with some fraction still illegally disposed.

Tire Production

Tires are among the most complex mass-produced composite materials in production today. They are constructed from a variety of engineered elastomeric sub-assemblies, including tread, sidewalls, bead seal, reinforcing textile plies, metal belts, liner, and shoulder wedge. Tire subassemblies contain natural and synthetic rubber, reinforcing fillers, oils, antioxidants, zinc oxide, accelerators, and sulfur (see Table 1). Each elastomeric blend is specially designed to meet various design goals, such as wear, durability, cushioning, noise and vibration dampening, traction, etc.

Tire Recycling

In California, recycled tire product means “a product with not less than 50 percent of its total content derived from recycled waste tires” (Public Resources Code Section 42890), while crumb rubber means “rubber granules derived from a waste tire that are less than or equal to, one-quarter inch or six millimeters in size” (Public Resources Code Section 42801.7). A “tire-derived product” refers to material “derived from a process using whole tires as a feedstock ... [using] shredding, crumbing, or chipping” (Public Resources Code Section 42805.7).

Among recycled and reused tires nationally, about 5 percent, are converted into crumb rubber. In California, almost 12 percent of waste tires are converted to crumb rubber (see Table 2). The major uses of crumb rubber include molded products (35 percent), sports surfaces (26 percent), and asphalt and sealants (20 percent); new tires (9 percent), horticultural uses (4 percent), and animal bedding (4 percent) (U.S. Rubber Manufacturers Association, 2004). The use of crumb rubber for the manufacture of tire-derived rubber flooring products falls under molded products or sport surfaces uses.

Table 1 Chemical compounds associated with tire production.

Material	Chemical Compound
Polymers	Natural rubber
	Styrene-butadiene rubber
	Cis-Polybutadiene copolymer
Vulcanizing agents	Sulfur
	Tetra-methyl thiurame sulfide
Accelerators	Diphenylguanidine
	2-Mercaptobenzothiazole
	n-Cyclohexyl-2-benzothiazolylsulfenamide
	2-(n-Morpholinyl)-mercaptobenzothiazole
	Hexamethylenetetramine
Activators	Zinc oxide
	Zinc carbonate
	Stearic acid
Antiozonants and Antioxidants	2,2,4-trimethyl-1,2-dihydroquinoline (polymer)
	n,n-(1,3-dimethylbutyl)-p-phenylenekiamine
	Paraffinic wax
	Akylphenols
	Resourcinol
	2,6-diterbutylhydroquinone
Retarders	n-Cyclohexylthiophthalimide
Plasticizer	Aliphatic oil
	Aromatic oil
	Naphthenic oil
	Di-(2-ethylhexyl)-phthalate
Extender	Silica gel
	Carbon black

Source: CIWMB, 2004.

Table 2 California waste tires disposal in 2006
(Millions of Passenger Tire Equivalents).

Reuse	2.1	Exported	1.9
Crumb Rubber	2.7	Agriculture & other uses ¹	3.2
Rubberized Asphalt Concrete (RAC)	3.9	TDF – Co-generation ²	1.3
Civil Engineering applications	3.3	TDF – Cement ³	7.0
Alternative Daily Cover (ADC)	4.5	Imported ⁴	1.4
Retread	4.4	Disposed ⁵	11.4
		TOTAL	44.4

Source: CIWMB, 2007a.

1. Applications include whole waste tires used in agriculture, as tarp weights for haystacks; ground waste tire rubber products such as athletic surfaces and running trails .
2. TDF (Tire-Derived Fuel) combusted in power plants.
3. TDF combusted in kilns for making cement.
4. Imported for fuel supplement or to generate crumb rubber.
5. ~25 of the 44.4 million tires generated disposed of in landfills.

Legislation Affecting Crumb Rubber

In 1991, the federal Intermodal Surface Transportation Efficiency Act (ISTEA) set into motion requirements to use an asphalt concrete with a 20 percent ground rubber content by 1997. In the following two years, more than 100 crumb rubber manufacturing facilities entered the market. But pressure from local governments and the asphalt industry resulted in Congress repealing this requirement in 1993, leaving the crumb rubber operations with an abundance of supply.

In 2005, the Governor signed legislation (AB 338, Levine, Chapter 709), which required the Department of Transportation (Caltrans) to phase in the use of crumb rubber asphalt on state highway construction and repair projects. The bill specifies that crumb rubber used must be derived from waste tires taken from vehicles owned and operated in the United States. The phase period starts January 2007 with “not less than 6.62 pounds of (crumb-rubber material) per metric ton of the total amount of asphalt paving materials used.”

Crumb Rubber Processing

Crumb rubber is made from waste tires by two primary methods: 1) ambient processing, 2) cryogenic processing. Ambient processing is the most common method: scrap tires are ground up mechanically into small pieces under ambient conditions. During cryogenic processing, scrap tires are frozen using liquid nitrogen and shattered into small pieces. One manufacturer (BAS Inc.) in California uses the cryogenic processing and claims that it is a cleaner manufacturing method. These two processes produce crumb particles with different particle morphology. Crumb rubber is classified by ASTM specification (D5644) into four categories:

- a. buffings – larger than 25 mm (1 inch)
- b. coarse – 25 to 5 mm (1 to 10 mesh)
- c. ground – 2 to 0.2 mm (10 to 80 mesh)
- d. fine-grind – 0.2 to 0.04 mm (80 to 400 mesh)

There are a number of processing techniques to manufacture flooring with crumb rubber particles (see review article, Myhre and MacKillop, 2002). These include molding and extruding mixtures to create newly aggregated forms, using adhesive binders. Binders are often composed of polyurethane precursors, liquid polymers, oligomers, resin adhesives, virgin polymers, and/or rubber curatives. In most cases, a percentage of crumb rubber is combined into convention rubber formulations or mixed with bonding agents for binding. Some sheet rubber used for flooring is made by calendaring natural and synthetic rubber with crumb rubber, followed by continuous vulcanization process. Sheets can also be made by extrusion processes that involve high heating of the rubber. Some rubber flooring is made by compression molding together two layers of rubber where the top layer is made from high-quality compound resistant to wear, and the base layer beneath is processed from lower cost material that can contain up to 80 percent crumb rubber content. Some flooring tiles are processed by re-bonding crumb with a urethane binder and adding pigments for color. These tile processes can be at room temperature, or heated.

Many components of tire production remain intact through the life of tire recycling, which largely entails mechanical grinding and separation of subassemblies (to produce crumb rubber), followed by annealing or molding. Many chemicals in the polymers, such as vulcanizing agents, accelerators, plasticizers, etc. (see Table 1) remain in recycled rubber. These chemicals are found in waste tire leachate, as well.

Tire-Derived Rubber (TDR) Flooring

Currently, tire-derived rubber (TDR) flooring is a small, but growing, sector of the floor coverings market. In 2003, carpet and area rug dominated with more than 60 percent of the flooring market; ceramic (tile) and vinyl flooring (sheet and tile) had 11 percent each. Rubber floorings are about 5 percent, and rubber laminates are at 2 percent. Rubber flooring includes mats, rolls, sheets, and tiles. Among the materials for flooring, rubber is one of the lower-priced options.

TDR-flooring products are produced chiefly from ground rubber, that is, 0.2-2 mm particles. Manufacturing of TDR flooring products has been developed and supported by CalRecycle through its grants program. The market development program is part of CalRecycle's effort to develop sustainable waste tire and green building materials market and has effectively diverted quantities of generated waste tires from disposal. As of 2006, 2.7 million waste tires in California were beneficially reused as crumb rubber in TDR flooring. As the TDR flooring market expands, more tires will be converted to crumb rubber to meet this need.

Environmental and Health Risks

Chemicals Released from Tire-Derived Rubber

Most of the studies on the environmental and health effects of tire disposal have focused on disposal processes, such as combustion and landfill. At least 20 VOC compounds have been identified in tire-waste leachates; benzothiazole and methyl isobutyl ketone, both used in the production of rubber, were found in significant levels (Sullivan et al., 1992; Hartwell et al., 1998; US EPA, 2003, Gunter et al., undated). Laboratory leach tests found five different benzothiazoles in leachate; benzothiazoles are used in tire production to accelerate the vulcanization process, as antioxidants, and to help bond the metal wire and metal belts to the tire rubber (Kumata et al., 2002). Naphthalene was also found, which may have originated from the rubber's carbon black constituent. Phenol/formaldehyde is used to pretreat steel cords and fabrics in belts to assure good adhesion to the rubber. Petroleum oil compounds, including acetone, toluene, benzene, polycyclic aromatic hydrocarbons, methyl ethyl ketone and 2-methyl naphthalene, were reported as released in small amounts. These compounds are found in coal tar, a softener and extender additive used in rubber production. Small amounts of aniline, an inhibitor of rubber degradation, phenol from petroleum oils and/or coal tar fractions used as a softener and extenders in tire production, 4-(phenylamino)-phenol, phenoxazine, and 2(3H)-benzothiazolone were also found to be released. Tire production inhibitor compounds nitrosoamines (diphenyl and dimethyl) were also reported in leachate.

Exposure to carcinogenic polycyclic aromatic hydrocarbons has been identified for the crumb rubber workers (Watts et al., 1998). Birkholz et al. (2003) used *in vitro* mutagenicity assays to examine the human and ecosystem hazard related with use of recycled tire product in public playgrounds. The results suggested that the chemicals that cause ecotoxicity sharply decline or disappear after products aged for three months.

Emissions from Tire-Derived Rubber Products

Limited study has been made of air emissions products with recycled tire content. Chang et al. (1999) studied air emissions of rubberized athletic tracks containing shredded rubber (not recycled tires) and found that the emission of VOCs decreased with time. They found that after about two years, the levels at breathing heights were near background.

VOCs found in the air emissions of recycled tire products include aromatic hydrocarbons, aliphatic hydrocarbons, cycloalkanes, alcohols, ethers, aldehydes, ketones, halocarbons, and phenols (Sullivan et al., 1992). Toluene, benzene, acetone, naphthalene, and phenol were also found in air emissions; these are used as tire softeners and extenders. Benzothiazole is a predominant emission from TDR material (Reddy and Quinn, 1997; Kumata et al., 2002). Methyl isobutyl ketone is used in the manufacture of rubber antioxidants, which protect rubber products from degradation by atmospheric ozone (Gunter et al., undated).

The 2003 emissions study identified a number of chemicals that are emitted by tire-derived flooring products. Naphthalene was the only chemical emitted at levels that would lead to air concentrations above the California chronic reference exposure limits. Several other chemicals of concern were identified at lower levels, including ethylene glycol monobutyl ether, 1-methyl-2-pyrrolidinone, and pseudocumene. The emissions study reported large amounts of other chemicals also emitted from some tire-derived rubber flooring products, but many of these chemicals could not be fully identified. The potential impact of the many minor constituents and unknown chemicals on indoor air quality led to the emission study's recommendation that rubber-based products not be promoted for wide use in most indoor environments until further studies are done.

There has been limited examination of the exposures from TDR products emissions of VOCs and the related risk from human inhalation. Chemical releases from recycled rubber include compounds generally originate from rubber production, such as softeners, extenders, anti-oxidants, solvents for processing, and vulcanization accelerators (refer back to Table 1).

OEHHA recently conducted a review on exterior rubberized surfacing containing recycled waste tires (CIWMB, 2007b). Such surfacing is used in playgrounds to help prevent serious fall injury to children and in tracks to provide a comfortable, all-season running surface. This study evaluated the potential health risks to children from the chemicals released by these surfaces. OEHHA concluded that the generally low levels of chemicals released by these surfaces were unlikely to cause adverse health effects in children. With TDR products deployed outdoors, emissions generally do not lead to high concentrations or exposures in the outdoor air. No assessment was made of the possible air exposures to the chemicals released if playground materials were installed indoors.

Reference Exposure Levels

Under California Air Toxics Hot Spots Program (OEHHA, 2009), OEHHA is responsible for developing and publishing risk assessments to support health standards for chemicals posing potential health threat from short-term (acute) or long-term (chronic) exposures. Chronic Reference Exposure Levels, or cRELs, are air concentrations that are determined as "safe" for continuous (24 hour/day) exposure for the general public, including sensitive individuals, over a greater portion of a 70-year lifetime. Acute RELs, or aRELs, are "safe" levels based on infrequent, one-hour exposures. Both exposure levels address health effects excluding cancers. Exceeding the "safe" air concentration level does not necessarily mean that noncancer health effects will occur, but the likelihood of health effects increases as the air concentration rises above the "safe" level. The modeled concentrations estimated from the flooring emissions data can be compared to these REL concentrations to see whether emissions of these chemicals are likely to cause health effects.

One of difficulties of assessing the non-cancer health risks from chemicals emitted by tire derived flooring and other products, is there are little toxicity data on many of the emitted chemicals. In addition, some of the chemicals of concern do not have health values for various reasons. CalRecycle separately contracted with OEHHA to develop indoor RELS (iRELs) for four

chemicals previously found in tire-derived materials that had sufficient toxicity data. The iREL is an air concentration that would be below the level at which health effects would not be anticipated to occur in the general population with repeated 8-hour exposures. The derivation of iRELs for the four chemicals (Ethylene glycol mono-N-butyl ether, N-Methyl-3-pyrrolidinone, Naphthalene, and 1, 2, 4-Trimethylbenzene) is presented in Appendix E. *These iRELs are solely the product of the OEHHHA and have neither been reviewed nor endorsed by the Department of Health Services or the Public Health Institute. The iRELs are not part of any regulatory program and are advisory in nature. OEHHHA does not have control over the voluntary use of these iRELs by interested parties or organizations.*

Methodology

Testing of building products for air contaminant emissions includes many steps. It begins with the acquisition of a specimen from a known source with an identified manufacture date. Specimen packaging and handling need to be conducted by defined protocols and documented by chain-of-custody. Upon receipt by the laboratory, specimens are stored until sequencing of specimens begins with a pre-conditioning period in individual clean-air vessels. Emission tests are conducted in individual small chambers, with air samples collected at set times. Air samples are analyzed subsequently, using laboratory standard operating procedures to determine concentrations of volatile organic compounds (VOCs) and carbonyl analytes (including aldehydes) in the chamber during each test period. The chamber concentration data are used to calculate emission factors for analytes emitted from each specimen. In turn, these rates are used to estimate individual VOC exposure concentrations for specific model scenarios. The steps are described below, and reference documents are included in the Appendix B.

Flooring Product Acquisition

An outreach to flooring manufacturers was conducted to assemble information on all companies that produced rubber flooring products. Companies were contacted by correspondences, and by follow-up phone calls (see Appendix A). A subset of manufacturers was identified as willing to participate in the study. The identities of participating companies are kept confidential for this study, and only descriptive information about the individual products is included in this report.

A study objective has been to provide testing specimens that are representative of the product manufactured under typical production conditions. Instructions for manufacturer staff were developed to fully describe the protocols to be followed for their submissions of product specimens. These instructions are given in Appendix B1 and address the following elements:

- Collection and Shipping Schedule
- Acceptable Product Type and Manufacture Schedule
- Specimen Collection Procedures
- Specimen Storage and Shipment
- Chain-of-Custody Documentation
- Rejection of Specimens by Laboratory

Personnel at the company plant in charge of submitting specimens were instructed to read these instructions before starting, and requested to perform the tasks faithfully and conscientiously.

Specimen Emission Testing

The laboratory protocols followed in this study are based on California DHS Standard Practice (CA DHS, 2004). The Standard Practice was developed for *State of California Special Environmental Requirements Specification (Section 01350)* and requires 10 days of conditioning followed by four days of emission testing in small chambers. Notable to this study is the addition of long-term testing of flooring products. Following the 14-day protocol, products were returned to individual conditioning vessels. Subsequent chamber tests were conducted at 28 days, 60 days, and 90 days (i.e., post-Section 01350 start date). Details of the laboratory procedures are documented in Appendix B2.

Emission Test Chamber Descriptions

The laboratory used three kinds of small-sized chambers in its emission testing protocols (Figure 1). Chamber A was used for material conditioning including (a) for the initial (10 days) conditioning period, and (b) for the extended conditioning of specimens for the long-term tests (28, 60, and 90 days). Chamber B was used for the standard (Section 01350) four-day emission tests, i.e., specimens were loaded into these chambers at the end of the 10 day conditioning period. Tests were run at 24 hours (Day 11), 48 hours (Day 12), and 96 hours (Day 14). The chambers were operated within a constant temperature incubator. Chamber C was used for emission tests following the Section 01350 protocol, i.e., longer-term tests at 28, 60, and 90 days.

The emission test chamber configurations are summarized in Table 3. Clean air was conditioned through filtration/humidification processes and delivered to chamber at an air exchange rate (AER) of $\sim 1 \text{ h}^{-1}$ for all chambers. Exact flow readings were recorded and used in data calculations. Chambers B and C provided ports for aldehydes and VOCs sampling. The total sampling flow rate was below 75 percent of the chamber flow, to prevent possible leakage. Air humidity was controlled using mixing of dry and humidified airflows. Chambers A and C were located on the lab bench where the temperature was conditioned in the range of 68–73°F.

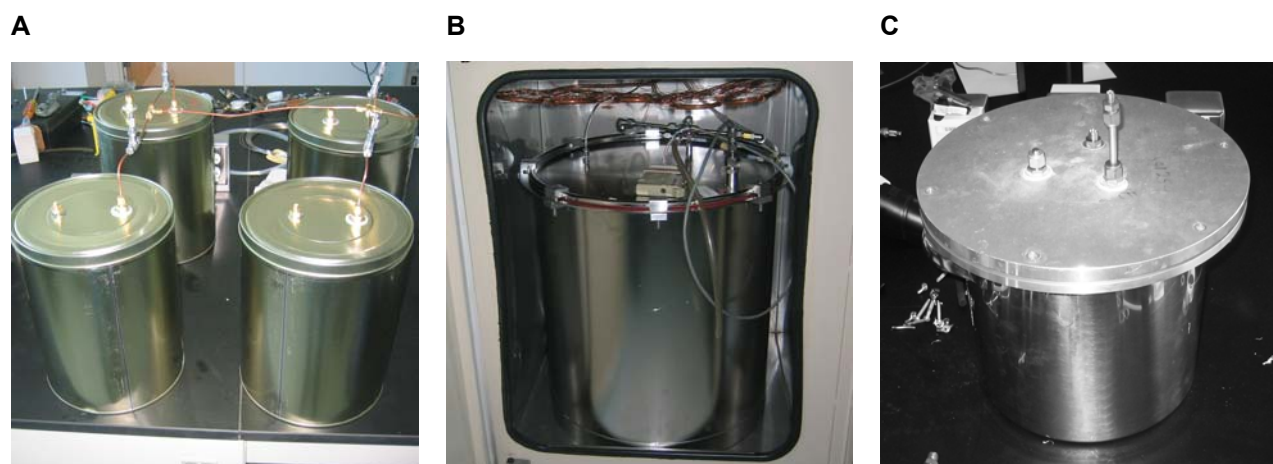


Figure 1 Emission test chambers used in the study.

Table 3 Emission test chambers for specimen conditioning and sampling.

Chamber	Volume (liters)	Testing use (location)	Chamber target flows ^(a)	Testing conditions ^(b)	Sampling media ^(c)
A (bench top)	16½	10-day and long-term conditioning	Q= 275 cc min ⁻¹ ACH=1 h ⁻¹ ±10%.	T=23±2°C; RH=50±10% Q/A=0.83 m h ⁻¹	n/a
B (incubator)	56	Section 01350 testing	Q=933 cc min ⁻¹ ACH=1 h ⁻¹ ±5%	T=23±1°C; RH=50±5% Q/A=2.88 m h ⁻¹	2 Tenax 2 DNPH
C (bench top)	12	Long-term testing	Q=200 cc min ⁻¹ ACH=1 h ⁻¹ ±5%	T/RH same as A Q/A= 0.60 m h ⁻¹	2 Tenax 1 DNPH

NOTES: (a) Q=chamber flow rate; ACH= air changes per hour; (b) T=temperature; RH=relative humidity; Q/A=specific loading factor (=m³ h⁻¹ per m² or m h⁻¹); (c) Tenax cartridge for VOC analyses; DNPH for carbonyl analyses (e.g., formaldehyde).

Ideally, identical chambers would have been used for all three components (i.e., conditioning, Section 01350, and long-term tests). However, because of the large number of flooring specimens to be tested, and the requirement to collect samples on a rigorous timeline (precisely at 11, 12, 14, 28, 60, and 90 days), this required separate chambers for the ~30 specimens to be continuously conditioned (till the end of 90 days). We acquired and used ~30 of the inexpensive chambers (A). However, at the time of the study, we were limited to two each of the large testing chambers (B) and smaller testing chambers (C).

Flooring Sample Preparation

Specimen preparation for conditioning and emission testing followed the *Standard Practice* (Section 3.5.5) for “sheet and tile type flooring products.” Individual pieces of the substrate were cut to a 6-by-6-inch square, then attached to a stainless steel plate sized to entirely cover the back surface of the specimen. Strips of low-VOC aluminized tape were used to attach the substrate to plate such that a 5.5-by-5.5-inch area of wear surface was exposed. Initial placement of the test specimen in the conditioning vessel (Chamber A) was regarded as the starting time for the sequence of emission tests (i.e., zero time).

Laboratory Analytical Methods

Stainless steel desorption tubes filled with TenaxTM sorbent were used to capture VOCs, and DNPH (2,4-dinitrophenylhydrazine) cartridges were used to collect aldehydes and other carbonyl compounds. Samplers were conditioned prior to use, and sampling flow rates were periodically calibrated. Duplicate sorbent tubes were collected for most samples; DNPH cartridges were duplicated ~10 percent of samples for quality assurance purposes. TenaxTM tubes are stored at room temperature, and DNPH cartridges were stored in freezer (-20° C) after sampling.

VOC Determinations

Thermal desorption (Perkin-Elmer ATD-400 or TurboMatrix ATD) and gas chromatography/mass spectroscopy (Varian Saturn 2200) were used to identify and quantitate VOCs collected on Tenax TA filled stainless steel tubes. Compounds within the range of volatility of n-Pentane (C₅H₁₂) to n-pentadecane (C₁₅H₃₂) were within the scope of this method. A mix of 60 compounds was injected at five concentration levels and response-concentration curves were developed for each of the 60 compounds. Calibrations were performed quarterly or as conditions merited. Peaks that were not calibration compounds were identified using the NIST Mass Spectra Library using a probability-based matching program and quantitated using the Total Ion Chromatogram response

of toluene. Peaks that were only tentatively identified were reported by chemical class (such as branched or aromatic hydrocarbon), if known, and a retention time. The method of quantitation was noted on the individual analytical reports. Samples were collected for 180 minutes at 50 cc per minute for a final volume of 9 liters. Chamber quantitation limits were 2 $\mu\text{g}/\text{m}^3$ for calibration compounds on the cREL, TAC or Proposition 65 lists; $\mu\text{g}/\text{m}^3$ for other calibration compounds and 10 $\mu\text{g}/\text{m}^3$ for non-calibration compounds. Performance tests were conducted in our laboratory of Tenax TA tubes to demonstrate there was effectively no breakthrough of selected compounds (e.g., benzene).

Techniques for Unidentified VOC Compounds

A lesson learned in the emissions study was that some TDR flooring materials emitted chemical compounds were unidentifiable using our GC/MS instrument and protocol. These samples generated chromatograms with large peaks that were not recognized by the mass spectral library at that time. In the current study, we employed two additional approaches in our attempt to determine identities for those heretofore unidentified chemical compound(s).

For several trials, a specimen was loaded into Chamber B, and several sorbent tubes were loaded over the period of a week. One tube was analyzed by GC/MS under standard conditions to verify that the presence of the peak; a second tube was analyzed using the expanded scan range of the GC/MS; and subsequent tubes were analyzed using the tandem mass spectroscopy (MS/MS) function. Peaks that were not positively identified by the mass spectral search algorithm were tentatively identified by chemical class, if known, and the peak retention time.

Another technique used stainless-steel canisters with internal surfaces treated to be chemically inert. Air is collected in 6-L evacuated canisters using a mass flow controller (300 cc min^{-1} for 20 minutes). The air sample from the canister was cryogenically focused, then analyzed by GC/MS (Varian Saturn 2200). The resulting chromatograms were searched against the NIST Mass Spectral Library and compared to a qualitative standard.

Carbonyl Compound Determinations

The sample volume collected on DNPH cartridges was 360 L (120 min x 300 cc min^{-1}). Duplicate cartridges were run for Chamber B. Because a lower flow was used in Chamber C, a single DNPH cartridge was used for the long-term samples. DNPH cartridges were extracted with acetonitrile, and carbonyl compounds (up to benzaldehyde) were analyzed using High Performance Liquid Chromatography with UV detection. A mix of seven carbonyl-DNPH derivatives at five concentration levels was used as calibration standards, and calibration verification standard was analyzed with each batch run. The estimated quantitation limits for individual carbonyl change for elution time, ranging from $\sim 4 \mu\text{g}/\text{m}^3$ for formaldehyde to $\sim 10 \mu\text{g}/\text{m}^3$ for benzaldehyde. Note: any carbonyl compounds C-5 and more reported were measured by ATD-GC/MS.

Microscopic Imaging

Microscopic imaging provides a useful tool for application like sample documentation, quality control, and examination of the composition of the specimens. Flooring samples were photographed using a low-power Leica Microsystems S6D stereomicroscope. Images were taken of the six-by-six-inch square sections used in the emission tests. For each sample, a 'spot' of the section was photographed at two magnifications (10x and 40x). The 10x image gives a broad picture of the product surface, while the 40x one displays greater detail. Each sample was photographed for top and bottom sides. The set of test product images are catalogued in Appendix C.

Data Analysis

Laboratory Data Quality

The study incorporated a hierarchy of quality assurance and quality control, from the sampling through the chemical analysis. The QA/QC included the following features:

- Flow rates on the samplers were calibrated prior to and after emission testing using a Primary Gas Flow Standard Calibrator (i.e. mini-Buck Calibrator®).
- Sampling information was recorded for each testing (shown in Appendix B).
- Sample media background checks: Tenax™ tubes and DNPH cartridges were analyzed prior to sampling to measure background contaminants on the samplers. For the aldehyde samplers, prior to sample extraction, a blank, unexposed sampler was extracted and analyzed to determine the background contributed by the extraction solvent. Aldehyde samplers were stored in the refrigerator until sampling began. Analysis of these blank samplers in parallel to test samplers served as a check on the sample contamination.
- Duplicate samples: During every 14-day emission testing, each chamber had duplicate Tenax™ samplers. About 20 percent of products (6 out of 32) were contemporarily sampled in two chambers. These duplicate samples provide a measure of the reproducibility of the method from sample preparation through analysis.
- For duplicate samples, *Relative Standard Deviation* (RSD) = s/x , where: s = standard deviation of four duplicate measurements; x = average of four duplicate measurements. A higher RPD indicates a great disparity between duplicate or replicate sample results.
- Emission factor measurements were evaluated for reproducibility and uncertainty. Duplicate chamber tests were simultaneously made for six individual products (labeled A and B), and duplicate Tenax cartridge tubes were collected for VOC analyses for most chamber tests (Figure 2). For paired results, the RSD was calculated using 14-d EF values of each major analyte.

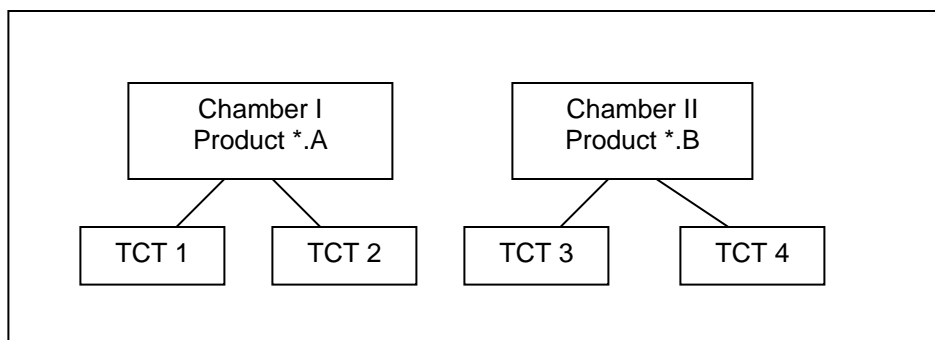


Figure 2 Duplicate chamber and Tenax cartridge tube (TCT) set-up.

Emission Factors

For each product specimen tested in the chamber, chamber concentration values are determined for all target compounds at various set times. The *emission factor* (EF) is the mass rate of an emitted chemical per area of material; it is calculated assuming steady state conditions in the chamber using the following equation:

$$EF = \frac{Q_C \cdot (C - C_o)}{A_C} \quad (\text{Eq. 1})$$

where: EF = emission factor [$\mu\text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$]
Q_C = chamber airflow rate [$\text{m}^3 \cdot \text{h}^{-1}$]
C = chamber concentration of the compound [$\mu\text{g} \cdot \text{m}^{-3}$]
C_o = background chamber concentration of the compound, generally zero
A_C = exposed area of the material in the chamber [m^2]

Because different chambers were used for short-term (24, 48, and 96 hours) versus long-term (28, 60, and 90 days) test samples, the estimate LOQs are different, despite consistent analytical performance in the laboratory. Hence, VOC analyte data are reported for EF > 10 and > 2 $\mu\text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$, for the short-term and long-term test samples, respectively.

Estimated Exposure Concentrations

When a source of VOCs is present in a room, the indoor air concentrations for emitted compounds can be estimated, using the same steady state assumptions given above. Modeled room concentrations are calculated based on parameters for the room setting, using the following equation:

$$C_m = \frac{EF \cdot A_t}{V_R \cdot ACH} \equiv K \cdot EF \quad (\text{Eq. 2})$$

where: C_m = modeled indoor air concentration of the compound [$\mu\text{g} \cdot \text{m}^{-3}$]
EF = emission factor of the compound from the material [$\mu\text{g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$]
A_t = exposure area of the material in the room [m^2]
V_R = room volume where material will be installed [m^3]
ACH = air change rate [h^{-1}]; note: V_R • ACH = Q_R [$\text{m}^3 \cdot \text{h}^{-1}$]
K = conversion factor for a given exposure scenario

A set of prototypical rooms were used to model indoor air concentrations for a range of exemplary settings where rubber flooring might be used and where exposure scenarios might be compared:

- *Daycare or nursery* classroom for pre-school children
- *Locker* or workout room adjunct to gymnasium or health club
- *State office* per 2003 emissions study
- *Typical classroom* per 2003 emissions study.

Table 4 lists the model parameters used for each exposure scenario. The state office and typical classroom exposure scenarios are the same as those used for the emissions study report. While it is not common to find TDR flooring in these rooms, they are included as points for comparison. More realistic are the daycare and locker room scenarios, because TDR flooring has performance characteristics that make it attractive in these settings: cushioned, non-slip, wear-resistant, etc.

The daycare and locker rooms are comparably sized, but we have presumed a daycare classroom in a residential building with no mechanical ventilation (under the current energy code, the target air exchange rate is 0.35 h^{-1}). In contrast, the locker room is presumed to be located within a mechanically ventilated building with an air exchange rate of 0.53 h^{-1} .

Loaded with an identical flooring product, the four scenarios yield a more than two-fold range of exposure concentrations. The conversion factor, K , can be applied to reported values of EF to convert to room concentrations for a given exposure scenario: Typical classroom (base case), state office (+13 percent), locker/workout room (+44 percent), and daycare/nursery classroom (157 percent). That is, air concentrations of contaminants emitted would be almost 50 percent higher in the locker/workout room and 150 percent higher in the daycare/nursery, as compared to the typical classroom.

Table 4 Exposure scenarios with parameters used to calculate room concentrations.

Scenario	Units	Daycare or Nursery for children	Locker or Workout Room	State Office	Typical Classroom
Flooring Area	m ²	37.2	37.2	11.1	89.2
	ft ²	400	400	120	960
Ceiling Height	m	2.6	3.0	2.7	2.6
	ft	8.5	10	9	8.5
Volume	m ³	96.3	113	30.6	231
	ft ³	3400	4000	1080	8160
Air changes per hour (ACH)	h ⁻¹	0.35	0.53	0.75	0.9
Conversion Factor (K)	h m ⁻¹	1.103	0.619	0.486	0.429

Chamber Size/Flow Rate Comparison

Reviewers of the draft report raised the concern about the test conditions used in Chamber C (long-term testing, 28 to 90 days) *vis á vis* Chamber B test conditions (14 days). While both use the same air exchange rates ($ACH=1\text{ h}^{-1}$), the specific loading factors (Q/A) are not matched (see Table 3). The concern raised was that the higher Q/A in the long-term test would cause a bias in emission factors. To test this, we performed side-by-side testing, where four identical specimens were prepared and placed into all four chambers at once. Two sets of previously tested products were chosen for these experiments. We chose products that emitted large amounts of calibration compounds and had sufficient material left to provide four test pieces. Product 6.3.2 and 7.2.1 met both criteria.

Product 7.2.1 specimens had large emission factors for cyclohexanone, meta/para-xylene and benzothiazole while Product 6.3.2 had large emission factors for methyl isobutyl ketone and benzothiazole. Product 6.3.2 specimens were placed into the chambers on a Friday afternoon to allow the chambers to equilibrate over the weekend. Inlet flow rates for each chamber were approximately one air change per hour per chamber. Each chamber was sampled three times the first week. On the second Friday of the experiment, a specimen from Chamber C (56 L) was placed in Chamber B (12 L), while the specimen from Chamber B went into Chamber C. Another set of specimens was kept in Chamber B and C for the entire experiment. The samples were pulled the following Tuesday, Wednesday, and Friday. The same experiment procedure was repeated with Product 7.2.1 specimens.

Results and Analyses

Products Tested

Between September 2005 and March 2006, 25 distinct flooring products from nine manufacturers were acquired and tested, including products of various colors, composition, sizes, and thickness (see Table 5). The total number of products tested was 32, which includes variant specimens (e.g., different color or thickness) and tests on products from later manufacturing lots. Table 6 gives the characteristics of the rubber flooring products tested in this study. Product IDs used in this study are a composite of information about the specimen: [Company id].[Floor id].[Lot id]. For example, Product 1.1.1 and Product 1.2.1 are two *different* flooring products produced by the *same* manufacturer (No.1). Product 6.2.1 and Product 6.2.2, are the *same* flooring products manufactured in *different* lots (i.e., on *different* dates) by the manufacturer (No. 6). We tested 10 products in duplicate, and four products received from separate lots, i.e., Product IDs 3.1.x, 3.2.x, 6.3.x, and 8.2.x.

The products tested in this study were observed in two types of composition, “homogeneous” and “layered” (see Figure 3). The former composition is generally elastic rubber throughout, hence the flooring is the same top and bottom sides. In layered rubber flooring, there is a thinner top layer with a thicker backing. Manufacturers utilize a vulcanization process that created the two-ply construction incorporating a resilient rubber top layer and an elastic rubber bottom layer.



**Figure 3 Photos showing cross-sectional views of rubber flooring
(a) homogeneous (ID 3.2) and (b) layered composition (ID 5.1).**

Four forms of flooring product were acquired: rolls, tiles, panels, and pavers. The typical specimen was taken from a standard tile (2-ft. or 3-ft. square). Thickness ranged from thin acoustic underlayment (2 mm) to thick barn pavers (60 mm), although the most common product was the 8- and 9.5-mm athletic flooring. The color was defined as the color of the rubber used in the product, separate from the “specks” often included in the resilient material.

The percentage of recycled rubber in the product varied from 0 to 100 percent. Manufacturers reported they used crumb rubber (not “buffings”) as the TDR type in their products. Manufacturing dates were reported by the company staff in the chain-of-custody form provided by the study staff (documents were also available to be downloaded from the project website).

Table 5 Characteristics of rubber flooring product (n=25) tested in study.

Characteristic	Parameter Value/Type	Number
Manufacturer	California	1
	Elsewhere in U.S.	6
	Canada	2
Form	Tile: 24"x24" or 38"x38"	13
	Roll: 30" or 48" wide	7
	Panel: 48"x96"	2
	Pavers: 30" or 48" wide	3
Composition	Homogenous	16
	Layered	9
Primary Use	Indoor	16
	Exterior	5
	Acoustic Underlayment	4
Thickness	2 mm	2
	3 mm	7
	6 mm	2
	10 mm	9
	25 mm	3
	50-60 mm	2
Color	Black	11
	Grey/Black-Grey	6
	Tan	3
	Other	5
TDR Content	91-100%	5
	81-90%	10
	61-80%	2
	Up to 10%	2
	None	6

Table 6 Description of rubber flooring products tested in study, grouped by rubber-type and primary use.

Rubber (a)	TDR (b)	Thickness (mm)	Form	Size	Comp. (c)	App. (d)	Use (e)	Color (f)	Product ID (g)	Dup (h)	Lot (i)	Mfr date
TDR	~65%	10	Tile	24"x24"	L	Sport	I	Blue-x	1.1.1	X		10-Oct-05
TDR	~65%	10	Tile	24"x24"	L	Sport	I	Grey	1.2.1			1-Dec-05
TDR	~85%	10	Tile	24"x24"	H	Sport	I	Black-x	6.3.1		X	11-Dec-05
TDR	~85%	10	Tile	24"x24"	H	Sport	I	Black	6.3.2			2-Feb-06
TDR	~85%	10	Roll	48" wide	L	Comm.	I	Black-x	7.1.1	X		22-Sep-05
TDR	~85%	10	Roll	48" wide	H	Sport	I	Black	8.1.1			8-Nov-05
TDR	~85%	10	Roll	48" wide	H	Sport	I	Black-*	8.2.1		X	22-Aug-05
TDR	~85%	10	Roll	48" wide	H	Sport	I	Black-*	8.2.2			8-Nov-05
TDR	~85%	6	Tile	38"x38"	H	Sport	I	Black-x	3.1.1	X		3-Oct-05
TDR	~85%	6	Tile	38"x38"	H	Sport	I	Black-x	3.1.2		X	24-Aug-05
TDR	~85%	6	Tile	38"x38"	H	Sport	I	Black	3.1.3			15-Feb-06
TDR	~85%	6	Tile	38"x38"	H	Sport	I	Black	3.1.4			15-Feb-06
TDR	~85%	6	Tile	38"x38"	H	Sport	I	Black-x	3.2.1		X	16-Oct-05
TDR	~85%	6	Tile	38"x38"	H	Sport	I	Black-x	3.2.2	X		27-Sep-05
TDR	~10%	3	Roll	55" wide	H	Sport	I	White-x	6.1.1			12-Dec-05
TDR	~10%	3	Roll	48" wide	H	Comm.	I	White-x	6.2.1	X		2-Feb-06
TDR	~85%	3	Panel	96"x48"	L	Acoustic	U	Black	7.2.1			1-Dec-05
TDR	~85%	3	Panel	96"x48"	L	Acoustic	U	Black	7.3.1	X		22-Sep-05
TDR	~85%	3	Roll	48" wide	L	Acoustic	U	Black	7.4.1			1-Dec-05
TDR	~85%	2	Roll	30" wide	H	Acoustic	U	Black-x	8.3.1	X		8-Nov-05
TDR	~100%	60	Pavers	22"x44"	H	Play	E	Steel	2.1.1		X	12-Oct-05
TDR	~100%	60	Pavers	22"x44"	H	Play	E	Steel	2.1.2			13-Oct-05
TDR	~100%	50	Pavers	9" hex	L	Barn	E	Tan	9.1.1	X		10-Jan-06
TDR	~100%	25	Pavers	24"x24"	H	Barn	E	Grey	4.1.1			14-Sep-05
TDR	~100%	25	Tile	24"x24"	H	Play	E	Green	4.2.1			14-Sep-05
TDR	~100%	25	Tile	24"x24"	H	Sport	E	Black	4.3.1			16-Oct-05
New	None	10	Tile	39"x39"	L	Comm.	I	Red	5.1.1			19-Jan-06
New	None	10	Tile	24"x24"	L	Sport	I	Grey-x	6.4.1			14-Dec-05
New	None	10	Tile	24"x24"	L	Sport	I	Grey	6.6.1	X		3-Feb-06
New	None	3	Tile	24"x24"	H	Sport	I	LtGrey-x	6.5.1			14-Dec-05
New	None	3	Tile	24"x24"	H	Sport	I	Tan-x	6.7.1			3-Feb-06
New	None	2	Tile	24"x24"	H	Comm.	I	Grey-x	5.2.1			18-Jan-06

NOTES: (a) Rubber–TDR=tired-derived. (b) %TDR reported by manufacturer. (c) Composition–H=homogeneous; L=layered. (d) Application listed by manufacturer. (e) Use–primarily U=underlayment; I=interior; E=exterior. (f) Color -x=incl.speckles; *=EPDM in specs. (g) Product ID=X.Y.Z – manufacturer X, model Y, and lot Z. (h) Dup=X – duplicate samples tested (A/B). (i) Lot=X – multiple lots of same model tested.

TDR flooring products have broad applications for their use in indoor and outdoor environment, and are often selected due to their slip-resistant, anti-fatigue, or acoustical damping characteristics. Products tested were divided amongst three categories: interior only; interior or exterior; and acoustic underlayment. In the indoor environment, application areas include health care centers, schools, retail shops, various industrial, health clubs, ice rinks, stadiums, and airports. Many of the TDR products intended for indoor applications can also be used outdoors. Interior/exterior products are frequently used around play structures in daycare centers, schools, and play areas in malls. Products used in outdoor environments include livestock trailers, gardens, markets, boat docks and ramps, golf courses, and trails. Some products are used as acoustic underlayment between concrete or plywood sub-floors and hard surface floor coverings, such as ceramic tiles, natural hardwood, or laminate hardwood.

Microscopic Visualization of TDR Flooring Products

Microscopic imaging of TDR flooring specimens provides a unique window into the characteristic similarities and differences among products. Fibers were observed in the images of several specimens, Products 4.1, 4.2, 7.1, 7.2, 7.3, and 7.4. Figure 4 showed images of two specimens observed with fibers. According to the information provided by the manufacturers, these products consisted more than 80 percent recycled tires. Using the polarized light microscope, none of the fibers were found to be asbestos. It is likely some of the fibers are fragments of tire steel belts or synthetic belts.

Under the stereo-zoom microscope, layered flooring products displayed distinctly different forms for top and bottom layers. The flooring surface reveals a landscape of aggregated crumb rubber particles. Pores pock the surface, and their size and shape vary greatly, a function of the manufacturing processes, the form of the TDR, and the shape and composition of particles. Figure 5 showed examples of layered and homogenous flooring products. In the layered product, the resilient top layer has smaller pores, and the elastic bottom layer has larger ones. Flooring products with homogeneous forms displayed similar images for both views. A full set of specimen images is contained in Appendix C.

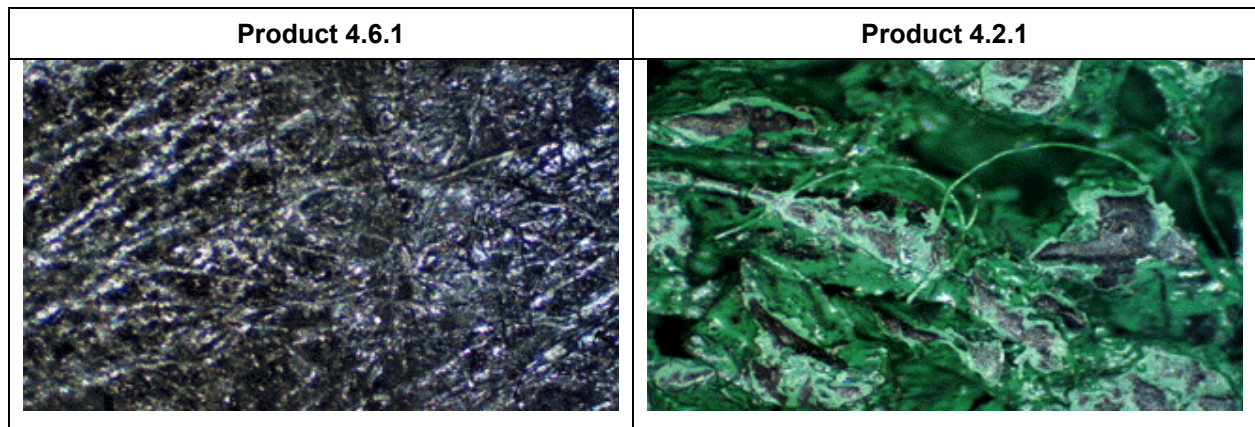


Figure 4 Images of embedded fibers in flooring materials (40x magnification).

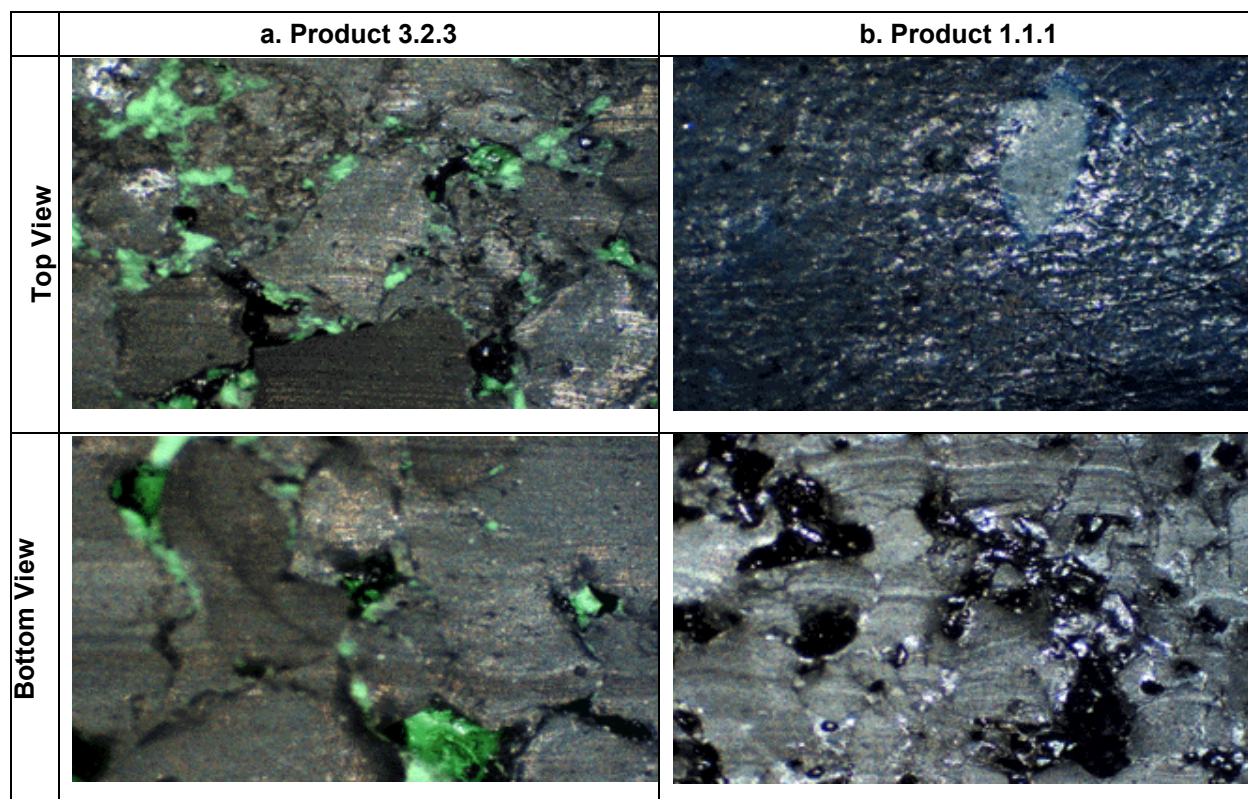


Figure 5. Top and bottom views of flooring products: (a) homogeneous and (b) layered composition (40x magnification).

Laboratory Data Quality

One goal of our quality assurance testing was to determine the reliability of the reported data. Uncertainties exist in both sampling and analytical procedures. Replicate measurements were taken to evaluate the uncertainties.

Sets of duplicate sample results are plotted in Figure 6. Each set shows four measurements for the two pairs (i.e., four cartridges for two chambers) of Tenax cartridge tube pairs used to measure 14-day emissions from duplicate flooring specimens (refer to Figure 2). The reproducibility of the measurements was evaluated using relative standard deviation (as percent of the mean or RSD); Table 7 shows RSDs of measurements for the major chemicals emitted. The chemicals were selected for the analysis when their emission factors were higher than the LOQ (i.e., $\geq 10 \mu\text{g m}^{-2} \text{h}^{-1}$). The paired cartridges showed very good agreement for most compounds detected. The RSD for duplicate samples was predictably higher, although for most chemicals, the RSD for duplicate samples was below 20 percent, indicating the uncertainty is relatively small. When emission factors are close to the detection limit, however, small absolute differences can have a substantial effect on RSD values, while for chemicals with higher emission factors, such as benzothiazole, the RSDs were quite small. The RSD for replicate pairs (two samples of the same is generally lower

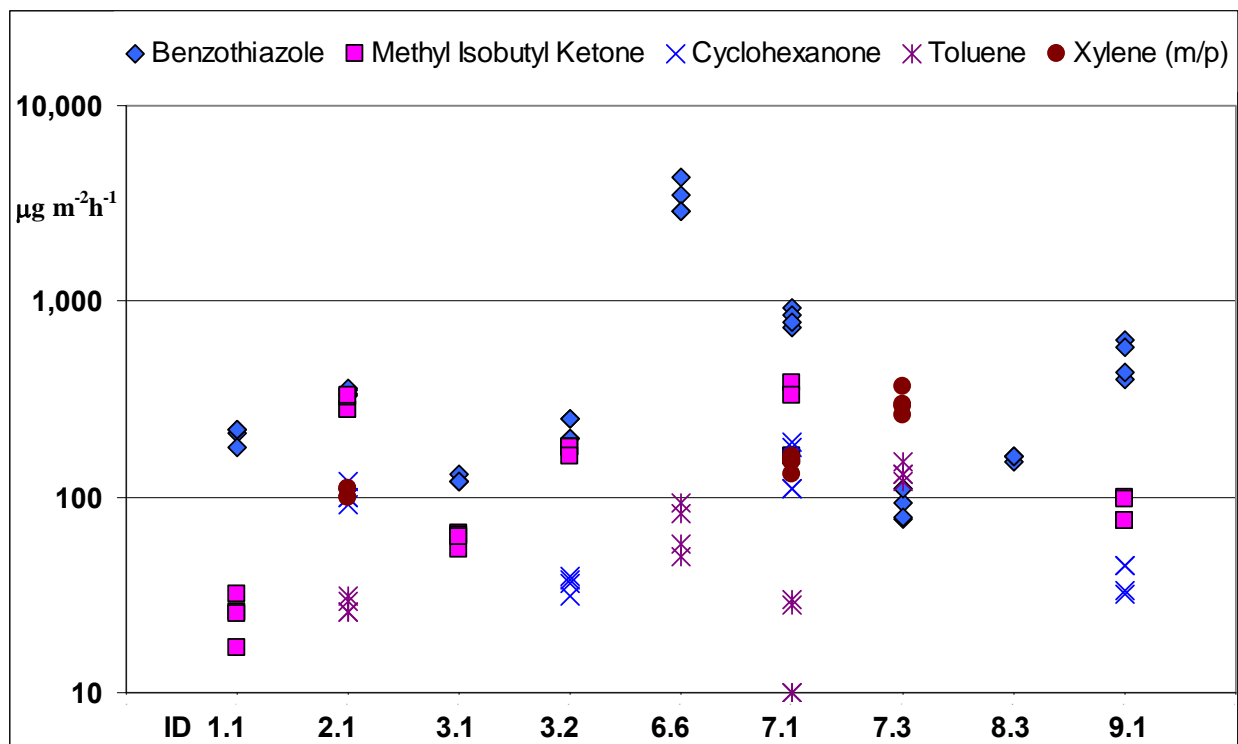


Figure 6 Emissions of major compounds for 14-day replicate measurements

Table 7 Relative standard deviation (RSD) of 14-day emission measurements

Compound	N pairs (a)	Mean Emission Factor ($\mu\text{g m}^{-2}\text{h}^{-1}$)	RSD cartridge pairs (b)	RSD sample duplicates (c)
Benzothiazole	18(9)	654	6%	10%
Methyl Isobutyl Ketone	12(6)	151	6%	20%
Cyclohexanone	8(4)	81	5%	20%
Toluene	8(4)	63	5%	30%
Xylene (m/p)	6(3)	186	6%	9%
Carbon disulfide	10(3)*	18	14%	1%
Styrene	5(2)*	15	10%	16%
Ethylbenzene	4(2)	25	6%	9%
Benzene	4(2)	25	9%	34%

NOTES: (a) number of pairs of replicate (duplicate) values. (b) RSD (standard deviation divided by the mean) for cartridge pairs. (c) RSD for duplicate sample pairs.

* missing data for duplicate pairs.

Emission Factors

A set of emission factors was determined over the time following conditioning: 11 days, 12 days, 14 days, 28 days, 60 days, and 90 days. The former three times are the “24 hour, 48 hour, and 96 hour tests” under the *Section 01350* protocol, while the long-term data were derived from tests taken after extended conditioning. Individual specimen data for VOC emission tests are tabulated in **Appendix D**.

Maximum Emission Factors

The data set is summarized for 14 to 90 day results in Table 8, Table 9, and Table 10, which show the maximum EF for each analyte at each sampling interval. They identify how many tested products emitted this chemical in substantial amount, and which product had the maximum emission factor (at 14 days). These results are tabulated to identify the *worst case* for each chemical source among the tested flooring products. They are intended to provide an overview of chemical emissions from TDR flooring products—a way to see which chemicals are the key components, how high their emissions can be, and whether they are common or rare among the tested products.

Table 8 includes the maximum emission factors of compounds that were most often found (5+) in flooring product emissions. Numerous compounds are emitted from some subsets of the samples, though not detectable in many other products. Table 9 shows the maximum emission factors of compounds that had quantifiable emissions in only 1 to 4 samples.

Benzothiazole, methyl isobutyl ketone, and cyclohexanone were far and away the most substantial and prevalent VOCs emitted from rubber flooring products. One or more of these three compounds had emissions $>100 \mu\text{g m}^{-2}\text{h}^{-1}$ for all the specimens. Carbonyls (acetone, acetaldehyde, and, for a lesser number, formaldehyde) were emitted from most products. Moderate emissions of carbon disulfide, ethylbenzene, and styrene were measured in almost half of the samples, while xylenes and toluene were emitted at very high rates for just a few specimens.

The highest emissions of many VOCs were often associated with a small subset of products. Product 10.1 is a 50-mm thick paver marketed for use in barns and horse trailers. Product 7.1 is a 9.5-mm layered flooring product. Products 4.1 and 4.2 are 25-mm thick exterior products. Product 6.4 and 6.6 are NR products marketed for interior use; these 9.5-mm thick layered products had substantially higher emissions than some of their homogeneous counterparts.

Table 10 lists the maximum emission factors of compounds for which we were able only to determine the chemical class or fully eluded our attempt to identify. Certain groups of chemicals measured in many TDR products were identified as isomers of branched, cyclic, or aromatic hydrocarbons. Identification of individual isomers in these hydrocarbons can be difficult as they have very similar mass spectra within each class. Conclusive identification is generally not possible without the calibration standard for each isomer. For the purposes of this report, unresolved hydrocarbons were labeled by their class and retention time (see Appendix D, e.g., “Branched HC (Rt: 21.4)” where the “Rt” is the retention time to the nearest tenth of a minute).

Table 8 Maximum chemical emission factors found in flooring specimens (in five or more).

Analyte	Day 14 (a)			Day 28 (a)			Day 60 (a)			Day 90 (a)		
	Count (b)	Product ID (c)	Max EF (d)	Count	Product ID	Max EF	Count	Product ID	Max EF	Count	Product ID	Max EF
Benzothiazole	38	6.6.1	3900	32	6.6.1	960	32	6.5.1	810	33	6.6.1	570
Methyl isobutyl ketone	30	4.2.1	1700	24	6.3.1	92	26	9.1.1	71	24	2.1.1	46
Acetaldehyde	30	2.1.1	47	14	6.4.1/ 9.1.1	9	21	4.3.1	7	17	2.1.1	8
Acetone	26	7.1.1	100	9	6.4.1	28	22	4.3.1/ 6.1.1/ 6.2.1	16	20	6.4.1/ 9.1.1	18
Cyclohexanone	25	4.2.1	510	24	2.1.1	42	20	7.1.1	40	21	9.1.1	36
Carbon disulfide	17	6.4.1	270	21	6.4.1	45	9	6.4.1/ 7.1.1	5	7	7.1.1/ 2.1.2	4
Toluene	16	4.2.1	1900	12	6.6.1	51	9	6.6.1	21	9	6.6.1	13
m/p-Xylene	16	4.2.1	2900	18	7.1.1	39	18	7.3.1	56	17	9.1.1	34
Styrene	14	6.6.1	40	12	6.6.1	23	8	6.5.1	24	10	6.6.1	7
Ethylbenzene	12	4.2.1	780	6	2.1.1	19	14	6.3.2	35	10	9.1.1	34
Formaldehyde	12	2.1.1	29	9	8.3.1	7	12	8.3.1/ 2.1.1	6	9	9.1.1/ 2.1.1	7
Butylated hydroxytoluene	9	5.2.1	1500	7	5.1.1	110	8	3.1.4	300	8	8.2.2	92
Trimethylsilanol	9	2.1.2	51	10	5.1.1	31	3	2.1.2	16	7	2.1.2	20
Naphthalene	8	4.2.1	410	3	4.3.1/ 9.1.1	4	16	9.1.1	16	19	9.1.1	10
Tert-butyl isothiocyanate	8	7.3.1	180	8	6.6.1	62	5	6.5.1	19	3	6.6.1	12
Phenol	8	5.1.1	24	4	5.1.1	25	7	9.1.1	3	12	5.1.1/ 8.1.1	3
1,2,4-Trimethylbenzene	7	4.2.1	72	7	2.1.1	21	6	9.1.1	20	6	4.3.1/ 2.1.1	11
n-Undecane	6	3.1.4	50	4	1.1.1	18	4	6.6.1	18	7	1.1.1	17
N,N-dimethyl-formamide	6	7.1.1	41	9	7.2.1	14	4	7.1.1	6.3	3	7.1.1	3.3
o-Xylene	5	4.2.1	1600	5	2.1.1	20	5	2.1.1	6	3	2.1.1	4
Decanal	5	8.2.1	140	1	5.2.1	14	3	6.1.1	6	5	8.2.2	17

- a. Day 14 emissions for 56 L chamber; Day 28, 60, and 90 emissions for 12 L chamber.
b. Number of specimens with non-trace emission factors. Total of 38 specimens.
c. Individual product with the highest emission factors.
d. Maximum Emission factor ($\mu\text{g m}^{-2}\text{h}^{-1}$).

Table 9 Maximum emission factors for chemicals found in only four or less flooring specimens.

Analyte	Day 14 (a)			Day 28 (a)			Day 60 (a)			Day 90 (a)		
	Count (b)	Product ID (c)	Max EF (d)	Count	Product ID	Max EF	Count	Product ID	Max EF	Count	Product ID	Max EF
n-Decane	4	4.1.1	42	-	-	-	2	6.6.1	13	4	1.1.1/ 6.7.1	6
Nonanal	4	6.6.1	69	3	5.2.1	29	3	6.1.1	25	8	6.6.1	32
Benzene	4	7.1.1	56	2	7.1.1	16	8	7.1.1	13	6	7.1.1	4
n-Nonane	3	4.2.1	38	3	1.1.1/ 2.1.1	4	1	6.6.1	4	-	-	
Hexanal	2	4.2.1	57	-	-	-	-	-	-	3	7.4.1	14
1-Ethyl-4-methylbenzene	2	2.1.1	46	5	2.1.1	27	4	6.6.1	11	6	2.1.1	11
Propionaldehyde	2	2.1.1	51	2	-	-	1	2.1.1	5	1	2.1.1	7
1-Methyl-2-pyrrolidinone	2	2.1.1	100	1	2.1.1	36	1	2.1.1	15	1	2.1.1	43
4-Phenylcyclohexene	2	6.6.1	11	3	1.1.1	4.8	-	-	-	-	-	
Acetophenone	2	6.3.1	200	2	6.3.1	130	2	6.3.1	17	-	-	
Methylene Chloride	2	4.1.1	54	-	-	-	1	4.3.1	3	-	-	
a-Methylstyrene	2	6.7.1	27	2	6.3.1	12	2	6.7.1	5	-	-	
Chlorobenzene	2	3.1.3	54	-	-	-	-	3.2.4	3	-	-	
1,3,5-Trimethylbenzene	1	4.2.1	26	3	2.1.1	7	3	6.6.1	11	2	6.7.1	5
1,2,3-Trimethylbenzene	1	4.2.1	27	2	9.1.1	4	2	9.1.1	9	1	4.3.1	5
Isopropyl Alcohol	1	6.5.1	20	4	6.5.1	5	2	2.1.2	3	2	2.1.2	3
Pentadecane	1	2.1.1	19	-	-	-	-	-	-	1	2.1.1	6
n-Octane	1	4.2.1	27	-	-	-	-	-	-	-	-	-
Octanal	1	3.1.4	41	2	5.2.1	26	1	6.3.1	7	4	8.2.2	26
Pentanal	1	4.2.1	22	-	-	-	-	-	-	-	-	-
Butyraldehyde	1	6.3.2	32	2	5.2.1	8	-	-	-	-	-	-
Aniline	1	1.1.1	15	4	1.1.1	20	3	6.5.1	20	4	6.2.1	16
d-Limonene	1	6.6.1	17	1	6.6.1	10	-	-	-	1	6.6.1	4

- a. Day 14 emissions for 56 L chamber; Day 28, 60, and 90 emissions for 12 L chamber.
b. Number of specimens with non-trace emission factors. Total of 38 specimens.
c. Individual product with the highest emission factors.
d. Maximum Emission factor ($\mu\text{g m}^{-2}\text{h}^{-1}$).

Table 10 Maximum emission factors for chemicals classes (i.e., compounds not fully identified)

Analyte class	Day 14 (a)			Day 28 (a)			Day 60 (a)			Day 90 (a)		
	Count (b)	Product ID (c)	Max EF (d)	Count	Product ID	Max EF	Count	Product ID	Max EF	Count	Product ID	Max EF
Branched HC	27	2.1.2	620	10	2.1.1	240	23	6.7.1	180	34	6.7.1	85
Aromatic HC	17	6.2.1	660	15	6.2.1	76	33	6.1.1	280	23	8.2.2	37
Aromatic Alcohol	1	6.3.1	130				2	6.4.1	16			
Cyclic Alcohol	2	2.1.1	45	2	2.1.1	25	1	2.1.1	7.1	1	2.1.1	10
Cyclic HC	14	6.6.1	180	16	6.6.1	87	14	6.6.1	85	12	6.2.1/ 6.7.1	41
Unidentified	7	4.1.1/ 4.2.1	11000	3	1.1.1	140	1	7.1.1	23	3	1.1.1	64

- Day 14 emissions for 56 L chamber; Day 28, 60, and 90 emissions for 12 L chamber.
- Number of specimens with non-trace emission factors. Total of 38 specimens.
- Individual product with the highest emission factors.
- Maximum Emission factor ($\mu\text{g m}^{-2}\text{h}^{-1}$).

Emission Factors for Product Types

The flooring specimens in the study were acquired from the subset of rubber-flooring manufacturers who accepted our invitation to provide their most popular products for testing. The products with most combinations were included in the sampling pool. The typical flooring product tested was *homogeneous tile*, composed of *tire-derived rubber* for *interior* use, although a range of other products were also tested (see Table 5).

Emission factors (EF values for the 14 day test) of selected chemicals for all of the individual samples were compared across the different types of samples. Figures 7-12 compare emissions categorized by the key parameters: *Rubber type*, *Thickness*, and *Application*. All the figures use the same format: **TDR** and **NR** (i.e., tire-derived and new rubber, respectively) refers to *Rubber type*; the *Size* is given in mm, and **I** and **E** signify products primarily for interior use versus for exterior use; **U** is for acoustic underlayment for *Application*. Only one product for each duplicate pair is plotted (e.g., 6.6.1A).

Three chemicals were consistently emitted at the highest rates (~ 100 to $>1000 \mu\text{g m}^{-2}\text{h}^{-1}$) from tested flooring products: benzothiazole, methyl isobutyl ketone, and cyclohexanone (Figure 7). The emission factors for these chemicals varied by more than 10-fold from low-to-high (<100 to $>1000 \mu\text{g m}^{-2}\text{h}^{-1}$). NR flooring emissions for benzothiazole were the highest as a group, although these products emitted essentially none of the other two compounds. The thicker TDR flooring, primarily interior/exterior products had higher emissions of these compounds.

None of these compounds are identified on the OEHHA Chronic Reference Exposure Level (cREL) list. However, some chemicals on the cREL list were emitted at fairly high levels, and there is concern about the potential for health effects from exposures to these chemicals. Among the cREL chemicals, xylenes had the highest emission factors (Figure 8). A few interior products had moderate chemical emissions ($30\text{-}100 \mu\text{g m}^{-2}\text{h}^{-1}$) for the xylenes and naphthalene, while thick interior/exterior products (pavers) from one manufacturer (Products 4.y.z) had very high emissions. Ethylbenzene and toluene emission rates were also high among the thicker products. Butylated hydroxytoluene, however, was emitted primarily from the thin **Interior** products, especially among **NR** flooring (Figure 9). Acetaldehyde and acetone were emitted at moderate, and relatively consistent, rates across the products (Figure 10). Formaldehyde was absent for NR products and most interior-only products, but it was measured at moderate levels for all the interior/exterior products and two of the interior products.

Benzene and carbon disulfide were emitted at low amounts, with the exception of one individual interior product for each (Figure 11). Benzene was emitted from a TDR product (ID 7.1), and carbon disulfide from a NR product (ID 6.4). Neither of these two chemicals appears to be integral to the rubber or flooring production processes. It is our conjecture that they were contaminants in solvents used in the production of the TDR floorings products. We have observed that emission rates for the relatively more volatile compounds (e.g., benzene and carbon disulfide) reduce relatively quickly with adequate flush-out ventilation.

Some sample emissions contained components that defied full identification by our GC/MS techniques. Some subset of aromatic and cyclic alcohols and/or aromatic, branched, and cyclic hydrocarbons were found in most samples (Table 11). The 60-mm homogenous paver (ID 2.1) emitted $\sim 1,000 \mu\text{g m}^{-2} \text{h}^{-1}$ of unidentifiable hydrocarbons, the majority of which were more than a dozen “branched hydrocarbons.” One of the NR flooring products (ID 6.2) had large amounts of “aromatic hydrocarbons.” The emissions for the pavers (ID 4.1 and 4.2) had extremely large, unresolved peaks, which were quantified as more than $10,000 \mu\text{g m}^{-2} \text{h}^{-1}$ (as toluene). These

chemicals do not have available toxicological information that allow development of cRELs. Nonetheless, there is the potential for odor and irritancy effects.

“SumVOC” is the sum of all identified, semi-identified, *and* unidentified chemicals for a given product test. A wide range of VOC emission factors were measured; as a point of reference, the range of modeled room concentrations would be <500 to >10,000 $\mu\text{g m}^{-3}$ (using the Typical Classroom scenario). Interior products have VOC emission factors toward the lower end, though many emitting >1000 $\mu\text{g m}^{-3}$. However, several samples might be classified as VOC *super-emitters* (>2000 $\mu\text{g m}^{-3}$); these flooring products (ID 2.1, 4.1, 4.2, 5.1, 5.2, 6.6, 7.1, and 8.2) were distributed among the TDR and NR, as well as I and E products (Figure 12).

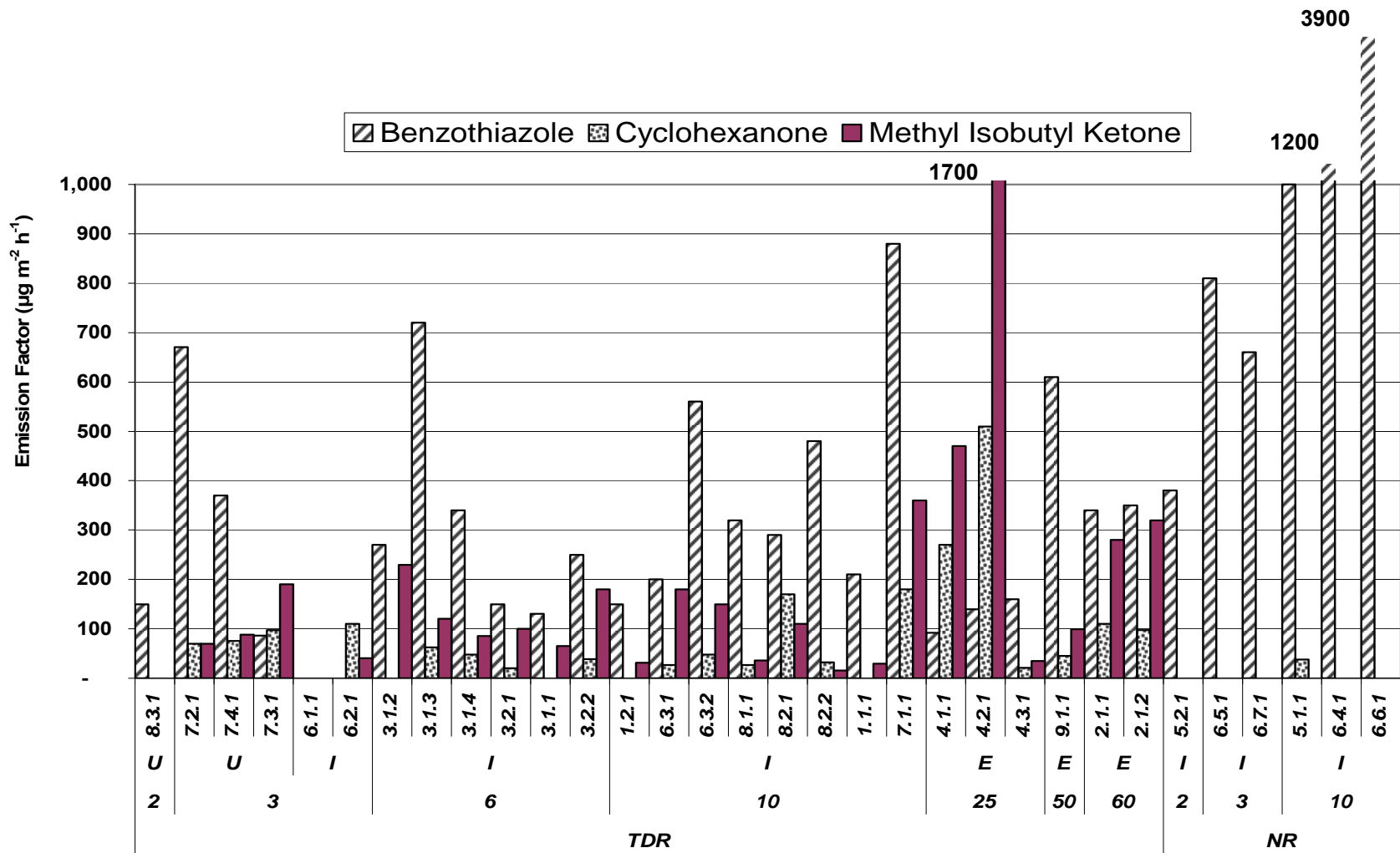


Figure 7 Emission factors at 14 days for samples by type: Benzothiazole, Methyl isobutyl ketone, and Cyclohexanone.

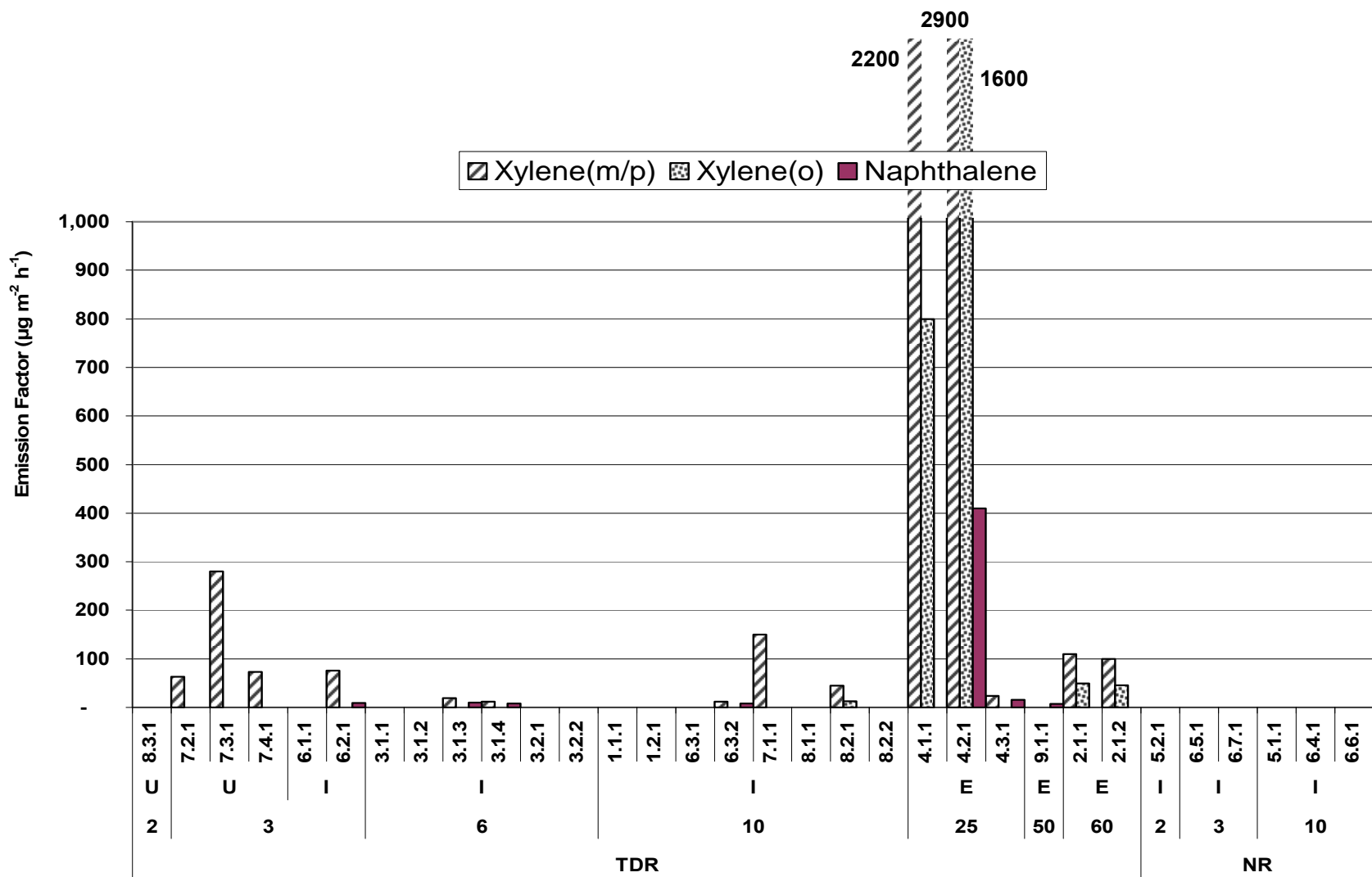


Figure 8 Emission factors at 14 days for samples by type: Xylenes and Naphthalene.

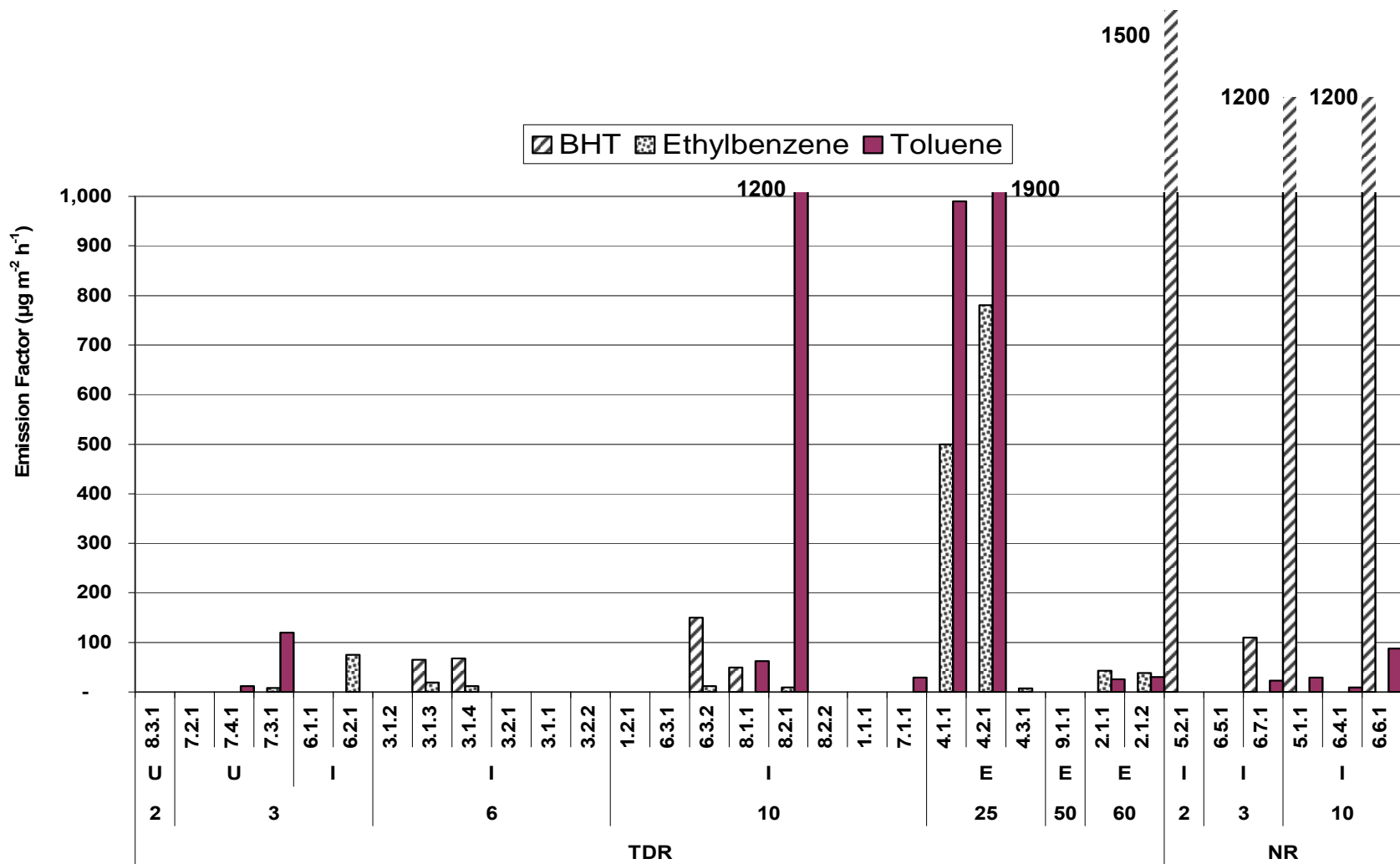


Figure 9 Emission factors at 14 days for samples by type: Butylated hydroxytoluene, Ethylbenzene, and Toluene.

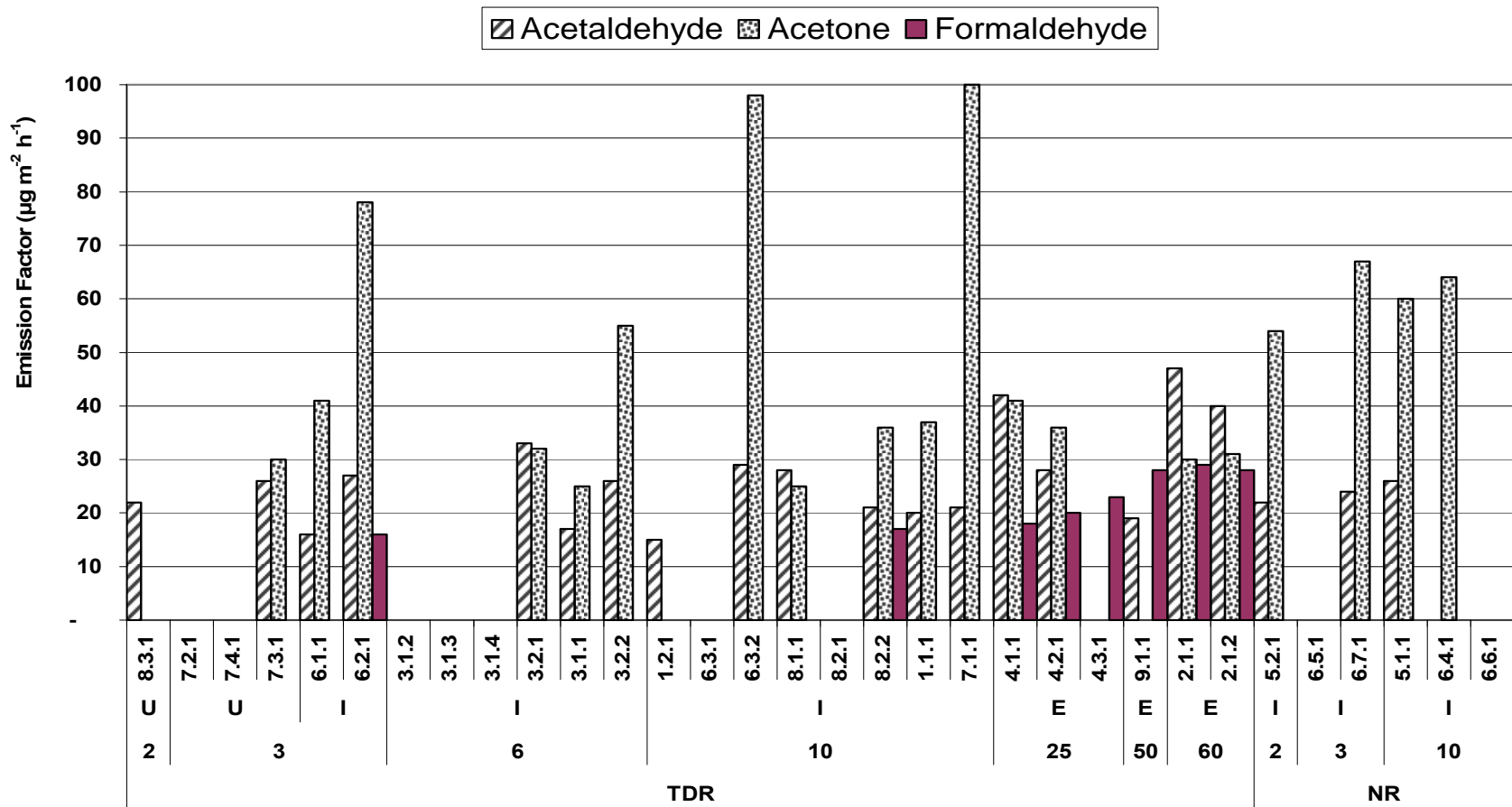


Figure 10 Emission factors at 14 days for samples by type: Acetaldehyde, Acetone, and Formaldehyde.

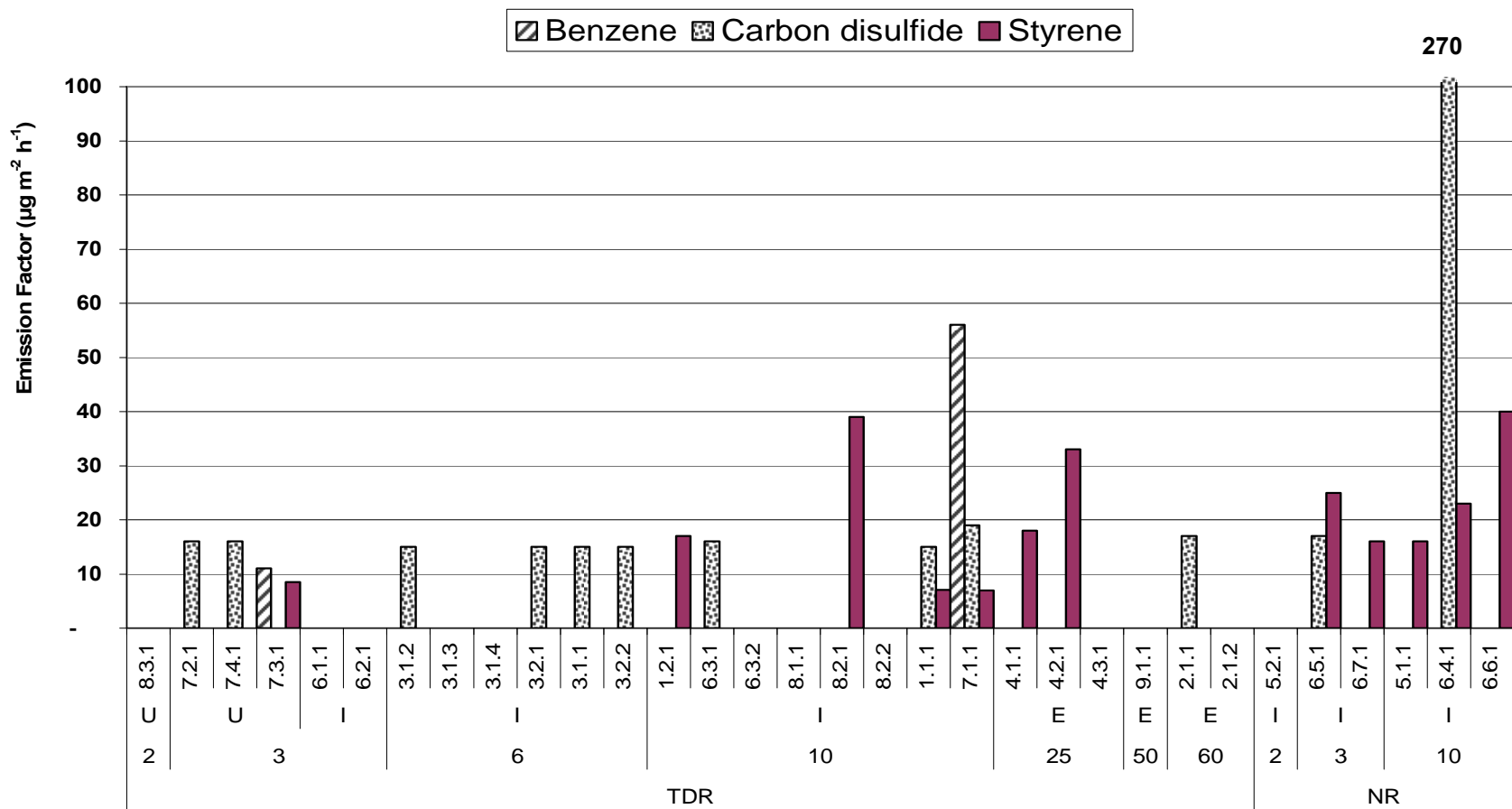


Figure 11 Emission factors at 14 days for samples by type: Benzene, Carbon disulfide, and Styrene.

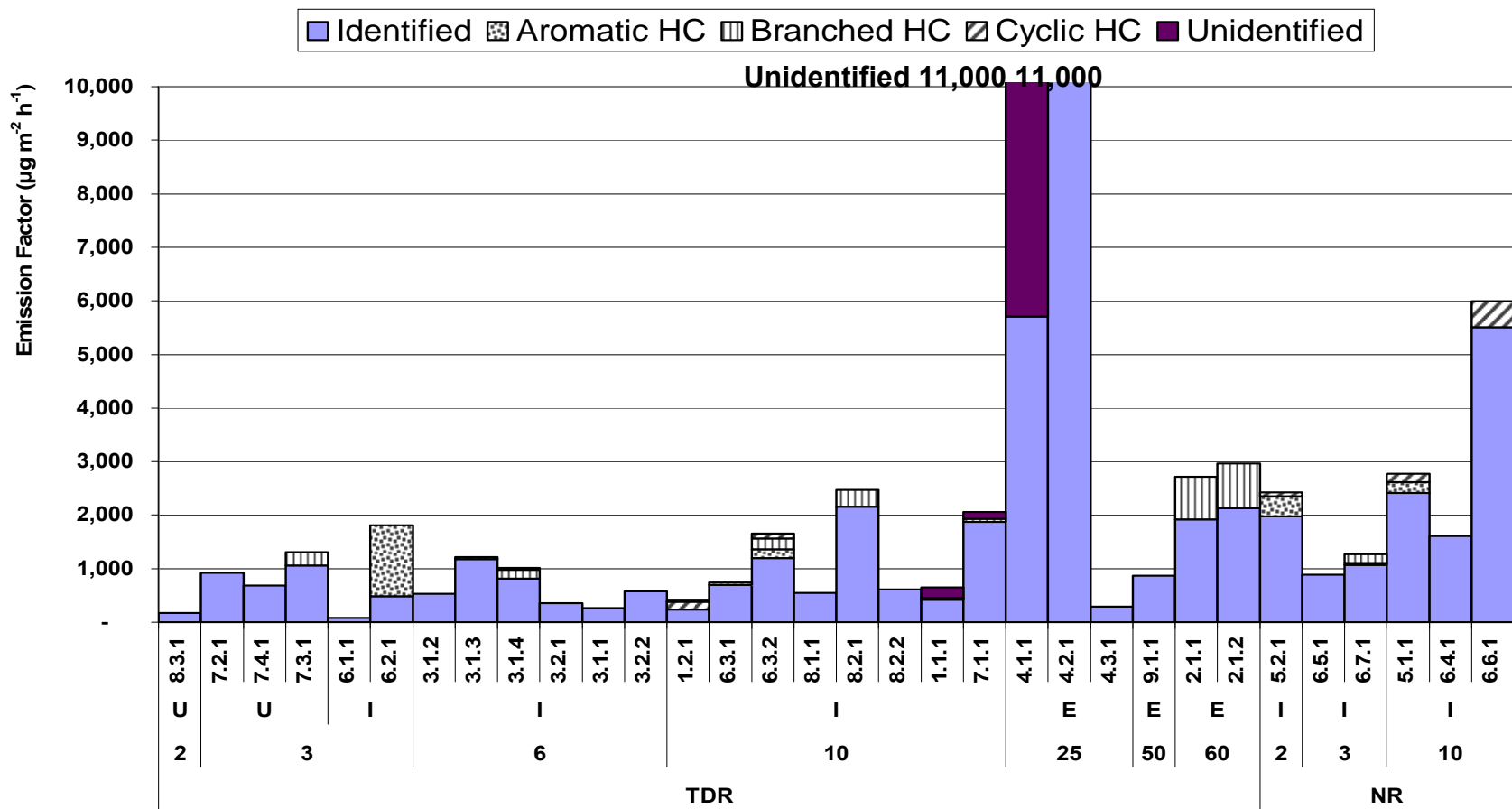


Figure 12 Emission factors at 14 days for samples by type: Semi-identified and Unidentified VOCs (added to Identified).

**Table 11 Total emission factors at 14 days from flooring samples:
Semi-identified and Unidentified VOCs.**

Rubber (a)	Thick ness (mm)	U s e (b)	Product ID	Aromatic Alcohol	Aromatic HC	Branched HC	Cyclic Alcohol	Cyclic HC	Unidentified	Sum VOC (c)	% Ided (d)
TDR	2	U	8.3.1							173	100%
	3	U	7.2.1							928	100%
			7.4.1							688	100%
			7.3.1			250				1,310	81%
		I	6.1.1							78	100%
			6.2.1		1,323					1,810	27%
	6	I	3.1.2							532	100%
			3.1.3		42					1,220	97%
			3.1.4			166	39			1,016	80%
			3.2.1							359	100%
			3.1.1							266	100%
			3.2.2							578	100%
	10	I	1.2.1					152	39	425	55%
			6.3.1	130	46					870	80%
			6.3.2		160	207	88			1,655	73%
			8.1.1							551	100%
			8.2.1			310				2,469	87%
			8.2.2							612	100%
			1.1.1				39		190	645	65%
			7.1.1			61			130	2,062	91%
	25	E	4.1.1						11,000	16,708	34%
			4.2.1						11,000	21,421	49%
			4.3.1							295	100%
	50	E	9.1.1							865	100%
	60	E	2.1.1			792		45		2,759	70%
			2.1.2			835		43		3,007	71%
NR	2	I	5.2.1		370		73			2,421	82%
	3	I	6.5.1							892	100%
			6.7.1		43	166				1,275	84%
	10	I	5.1.1		200		160			2,776	87%
			6.4.1							1,613	100%
			6.6.1				490			5,997	92%

NOTES: Emission Factors in $\mu\text{g m}^{-2} \text{h}^{-1}$.

(a) Rubber: TDR-tire derived; NR-new. **(b) Use:** I-interior; E-exterior; U-underlayment.

(c) SumVOC: sum of all identified and semi-identified and unidentified compounds.

(d) %-ID'ed: Percent of Total VOC emitted that were fully identified.

Exposure Scenarios and Modeled Room Concentrations

Chamber-derived emission factors were used to calculate room concentrations under a variety of exposure scenarios. Modeled room concentrations for the four scenarios are calculated from product emission factors of the individual flooring products and tabulated in Appendix D.

Table 12 and Table 13 show the maximum values (“worst cases”) for potential indoor air exposures. Indoor air concentrations were calculated using the maximum emissions factors values given above (e.g., Table 8). The VOCs of concern are listed with their cREL and odor threshold concentration values, in increasing order. Benzothiazole was identified with the highest emissions factors, but it does not have a cREL or odor impact.

For products used as exterior paver, some VOCs with health effects were found to have high emission factors (Table 12). The modeled concentration showed that the room concentration of xylenes, toluene, ethylbenzene, and naphthalene exceeded the cREL in the indoor scenarios such as daycare. For example, naphthalene was found to emit from some TDR flooring at levels that the maximum modeled air concentration ($451 \mu\text{g}/\text{m}^3$) would exceed the cREL value ($13 \mu\text{g}/\text{m}^3$) by a large amount. At this level there is an increased likelihood of adverse health effects occurring from naphthalene exposure. Naphthalene, in addition to its noncancer health effects, is also a carcinogen. The indoor exposure from naphthalene emitted from TDR flooring is likely to be quite small in comparison with the overall individual lifetime exposure, especially if the product is allowed to off-gas for a least a month before installation. However, it would be prudent to reduce naphthalene emissions from this product.

For most products used in the indoor environment, modeled VOCs concentrations were below the cREL. Only benzene was found in one case to have an emissions factors sufficient to cause the room concentration that might exceed the cREL (under the worst-case scenario and using the 14-day emission factor). There were a number of chemicals that have very low odor thresholds—thylbenzene, indene, methyl isobutyl ketone, and acetophenone—and modeled room concentrations for these compounds can exceed their odor thresholds even when they are emitted at low rates.

Table 12 Modeled room concentrations for four exposure scenarios – maximum case for Tire-Derived Rubber (TDR) *Interior-use* products.

Analyte	Product ID	Emission Factor @ Day 14 $\mu\text{g m}^{-2}\text{h}^{-1}$	cREL	Model scenarios			
				Daycare	Locker/ Workout Room	State Office	Classroom
				$\mu\text{g m}^{-3}$			
Acetaldehyde	7.1.1.B	38	140	42	23	19	16
Acetone	7.1.1.A	100		111	61	50	42
Acetophenone	6.3.1	200		221	121	100	84
Benzene	7.1.1.A	56	60	62	34	28	24
Benzothiazole	7.1.1.A	880		973	533	440	371
Butylated Hydroxytoluene	6.3.2	150		166	91	75	63
Butyraldehyde	6.3.2	32		35	19	16	13
Carbon disulfide	7.1.1.A	19		21	12	10	8
Chlorobenzene	3.1.3	54		60	33	27	23
Cyclohexanone	7.1.1.A	180		199	109	90	76
Decanal	8.2.1	140		155	85	70	59
n-Decane	8.2.1	28		31	17	14	12
Ethylbenzene	6.2.1.A	75	2000	83	45	38	32
Formaldehyde	8.2.2	17	9*	19	10	9	7
Methyl Isobutyl Ketone	7.1.1.A	360		398	218	180	152
a-Methylstyrene	6.3.1	20		22	12	10	8
Naphthalene	3.1.3	10	9	11	6	5	4
Nonanal	3.1.4	44		49	27	22	19
Octanal	3.1.4	41		45	25	21	17
Phenol	3.1.3	7	200	8	4	4	3
Styrene	8.2.1	39	900	43	24	20	16
Toluene	8.2.1	1200	300	1,326	726	600	505
1,2,4-Trimethylbenzene	8.2.1	28		31	17	14	12
n-Undecane	3.1.4	50		55	30	25	21
m/p-Xylene	7.3.1.B	330	700	365	200	165	139
o-Xylene	8.2.1	13	9	14	8	7	5

* cREL for formaldehyde is $9 \mu\text{g m}^{-3}$, the acceptance level used for Section 01350 screening is $33 \mu\text{g m}^{-3}$.

Table 13 Modeled room concentrations for four exposure scenarios – maximum case for TDR *Exterior-use* products.

Analyte	Product ID	Emission Factor @ Day 14 $\mu\text{g m}^{-2}\text{h}^{-1}$	cREL	Model scenarios			
				Daycare	Locker/ Workout Room	State Office	Classroom
				$\mu\text{g m}^{-3}$			
Acetaldehyde	2.1.1	47	140	52	28	24	20
Acetone	4.1.1	41		45	25	21	17
Benzothiazole	9.1.1.A	610		674	369	305	257
Carbon disulfide	2.1.1	17		19	10	9	7
Cyclohexanone	4.2.1	510		564	309	255	215
n-Decane	4.1.1	42		46	25	21	18
Ethylbenzene	4.2.1	780	2000	862	472	390	328
1-Ethyl-4-methylbenzene	2.1.1	46		51	28	23	19
Formaldehyde	2.1.1	29	9*	32	18	15	12
Hexanal	4.2.1	57		63	35	29	24
Methyl Isobutyl Ketone	4.2.1	1700		1,879	1,029	850	716
Naphthalene	4.2.1	410	9	453	248	205	173
Styrene	4.2.1	33	900	36	20	17	14
Toluene	4.2.1	1900	300	2,100	1,150	950	800
1,2,4-Trimethylbenzene	4.2.1	72		80	44	36	30
n-Undecane	4.2.1	26		29	16	13	11
m/p-Xylene	4.2.1	2900	700	3,205	1,755	1,450	1,221
o-Xylene	4.2.1	1600	700	1,768	968	800	674

* cREL for formaldehyde is $9 \mu\text{g m}^{-3}$, the acceptance level used for Section 01350 screening is $33 \mu\text{g m}^{-3}$.

Table 14 Modeled room concentrations for four exposure scenarios – maximum case for New Rubber (NR) *Interior-use* products.

Analyte	Product ID	Emission Factor @ Day 14 $\mu\text{g m}^{-2} \text{h}^{-1}$	cREL	Model scenarios			
				Daycare	Locker/ Workout Room	State Office	Classroom
			----- $\mu\text{g m}^{-3}$ -----				
Acetaldehyde	7.1.1.B	26	140	29	16	13	11
Acetone	7.1.1.A	80		88	48	40	34
Benzothiazole	6.3.1	3900		4,300	2,360	1,950	1,640
Butylated Hydroxytoluene	7.1.1.A	1500		1,660	910	750	630
Carbon disulfide	7.1.1.A	270		298	163	135	114
Cyclohexanone	6.3.2	38		42	23	19	16
Decanal	6.3.2	23		25	14	12	10
Isopropyl Alcohol	7.1.1.A	20		22	12	10	8
<i>o</i> -Methylstyrene	3.1.3	27		30	16	14	11
Nonanal	7.1.1.A	69		76	42	35	29
Phenol	8.2.1	24	200	27	15	12	10
4-Phenylcyclohexene	8.2.1	11		12	7	6	5
Styrene	6.2.1.A	40	900	44	24	20	17
Toluene	8.2.2	88	300	97	53	44	37
1,2,4-Trimethylbenzene	7.1.1.A	21		23	13	11	9

Discussion

Unresolved Chemical Compounds

In our routine gas chromatography/mass spectrometer (GC/MS) assays, many GC chromatogram peaks were not specifically identified by the mass spectral library. In these cases, GC retention time and MS spectrum can give enough information to classify them as an aromatic, branched, or cyclic hydrocarbon and the approximate number of carbons, e.g., C-9 branched hydrocarbon. Several more rigorous analytical techniques were tried to enhance identification of unresolved chromatograph peaks.

Products 1.1.1 and 1.2.1 each had a large peak with a retention time at ~ 9.9 minutes. This peak produced a mass spectrum with ions at 88 (100 percent), 86 (20 percent), 87 (15 percent) and 57 (7 percent) *amu* (atomic mass units). Product 7.4.1 had a large peak with a retention time of 35 minutes, with major ions at 243 (20 percent), 199 (100 percent), 111 (58 percent), 71 (21 percent), 43(35 percent), 41(27 percent) *amu*. The GC/MS scan parameters were changed in the region of interest to scan from 33 to 650 *amu* (the full range available), compared to the normal scan range (33 to 350 *amu*), to ensure that the mass spectrometer scan range was sufficient for the peak. We were hoping this would yield additional spectral information; however, in neither case did the expanded scan supply enough information to identify the peak.

A second task was to use our tandem mass spectroscopy (MS/MS) to scan on the major ions of these samples. With this technique, the mass ion of interest is isolated in the ion trap and then made to disassociate into smaller product ions. Structural information is obtained from formation of product ions. Freshly cut pieces of each specimen were placed in chambers B and several air samples from each product were taken. A tube from each specimen was analyzed over the extended mass range. The unidentified peak from Product 1.1.1 was present and again was not identified by the libraries. The unidentified peak from Product 7.4.1 was not detected in any of the air samples pulled. Product 1.1.1 was analyzed using the MS/MS scan. In this experiment, the 88 *amu* ion was isolated and made to disassociate into three ions (63, 62 and 61 *amu*).

Air samples were collected from Products 3.2.2 and 9.1.1 with stainless steel canisters on Day 13 of the 14-day test (in chamber B). The resulting chromatograms were compared to a qualitative standard and the mass spectral library. The comparison with Tenax cartridge tube results is given in Table 15. One objective of the canister sampling was to look for the presence of 1,3-butadiene, a chemical that cannot be collected on to Tenax. 1,3-Butadiene was not found in the canister samples.

Table 15 Comparison of results for two samples using Tenax and canister collection.

Product 3.2.2	Tenax cartridge tube		Canister	
Compound	Detected	Notes	Detected	Notes
Acetic Acid	No		Yes	
Benzene	No	Not detected	Yes	Small Amount
Benzothiazole	Yes		No	Rt > run time
Chlorobenzene	Yes		Yes	
Cyclohexanone	Yes		No	
Methyl isobutyl ketone	Yes		Yes	
Toluene	Yes	<LOQ.	Yes	
1,2,4-Trimethylbenzene	Yes		Yes	
1,3,5-Trimethylbenzene	Yes		Yes	
m/p-Xylene	Yes		Yes	
o-Xylene	No		Yes	Small Amount
Product 9.1.1	Tenax/Thermal desorption		Canister	
Compound	Detected	Notes	Detected	Notes
Benzene	No	Not detected	Yes	Small Amount
Benzothiazole	Yes		No	Rt > run time
Cyclohexanone	Yes		Yes	
Methyl isobutyl ketone	Yes		No	
a-Methylstyrene	No		Yes	
Styrene	Yes		No	
1,2,4-Trimethylbenzene	Yes		Yes	
m/p-Xylene	Yes		Yes	
o-Xylene	No		No	

Comparison of Emissions from Products Across Production Lots

As building products are being increasingly tested for their VOC emissions, this database continues to grow. It is increasingly being employed to determine the potential impacts of various building products on building IAQ. However, a one-time emission testing may not provide a true picture of chemicals off-gassing from the product *over time*. Results for a given product may not be reproducible in different production lots. The current study conducted emission tests on five sets of replicate lot samples (i.e., the same products manufactured at different times): Product 2.1.Z, 3.1.Z, 3.2.Z, 6.3.Z, and 8.2.Z. The major chemicals emitted at 14 days for products from different production lots are compared in Figure 13 to Figure 17 and Table 16.

The chemicals with the highest emission factors (e.g., benzothiazole, methyl isobutyl ketone, and cyclohexanone) were generally found with comparable emission factors among the lot samples, e.g., Product 2.1.Z (Figure 13) and Product 3.2.Z (Figure 15). However, some notable disparities are noted among the lot sets. Emissions of VOCs for Product 3.1.Z lot are shown in Figure 14. Product 3.1.3 and 3.1.4 emitted at higher rates for most chemicals. Carbon disulfide was found only in the emission of Product 3.1.1 and 3.1.2. Acetaldehyde and acetone were exclusively released by Product 3.1.1, while xylene (m/p) was only emitted by Products 3.1.3 and 3.1.4.

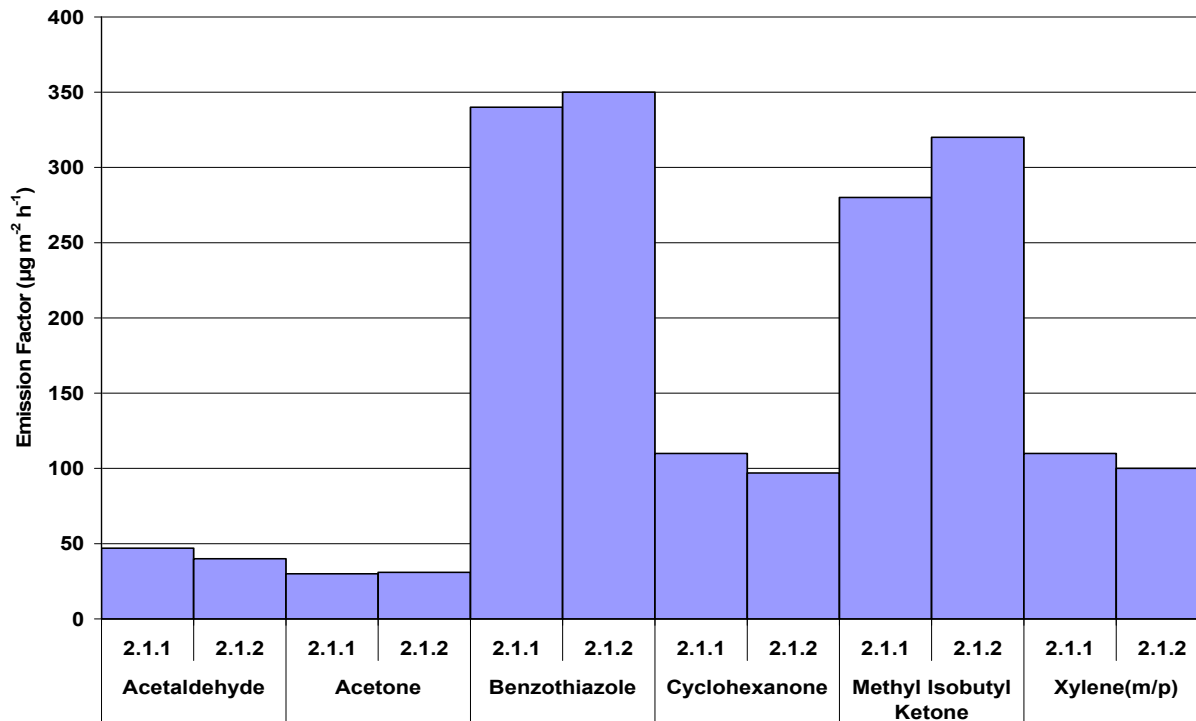


Figure 13 Emissions for two production lots of Product 2.1.Z.

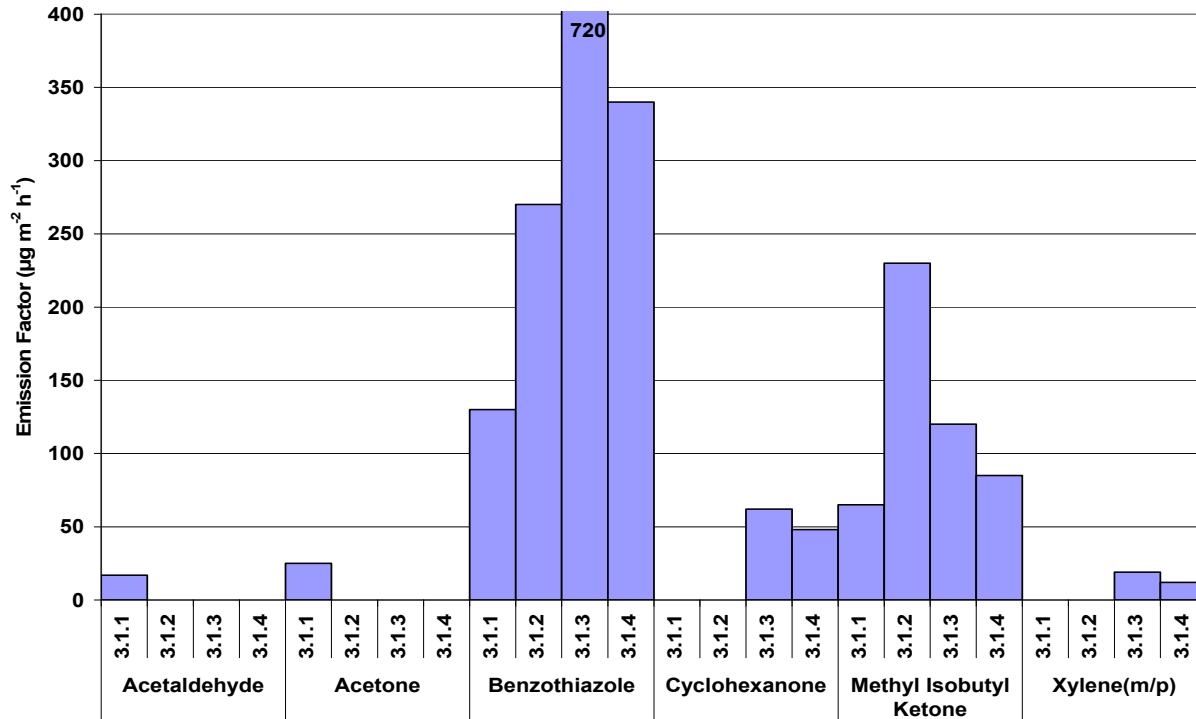


Figure 14 Emissions for four production lots of Product 3.1.Z.

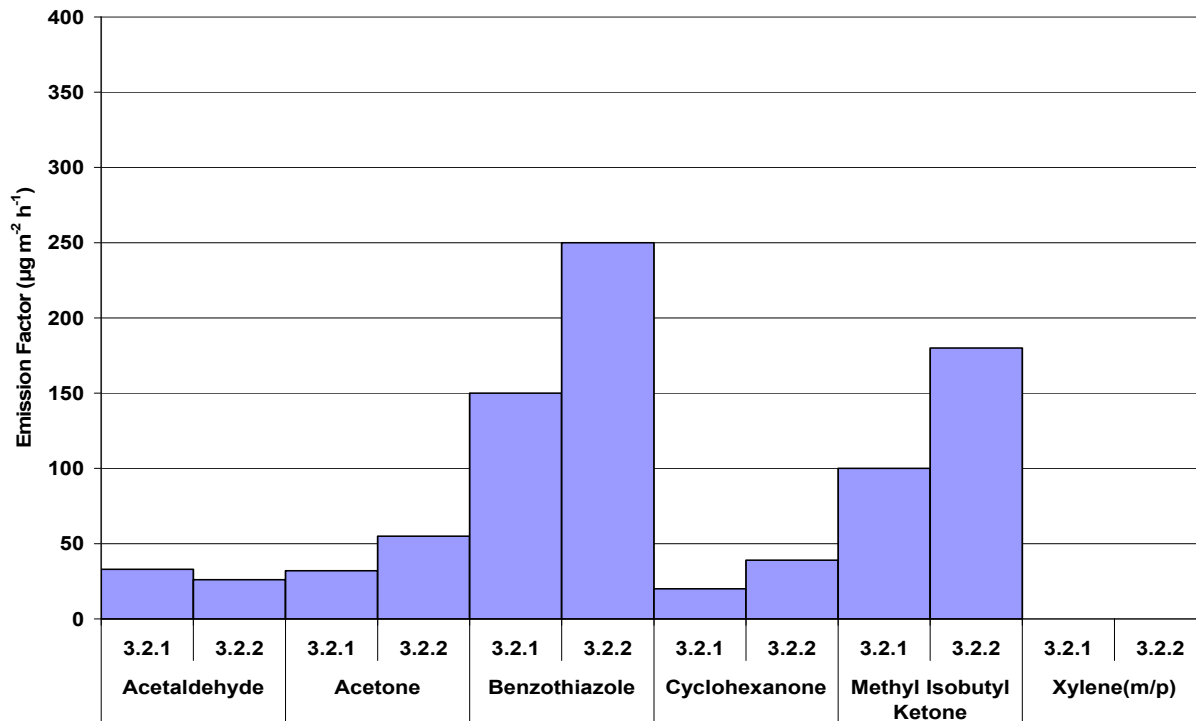


Figure 15 Emissions for two production lots of Product 3.2.Z.

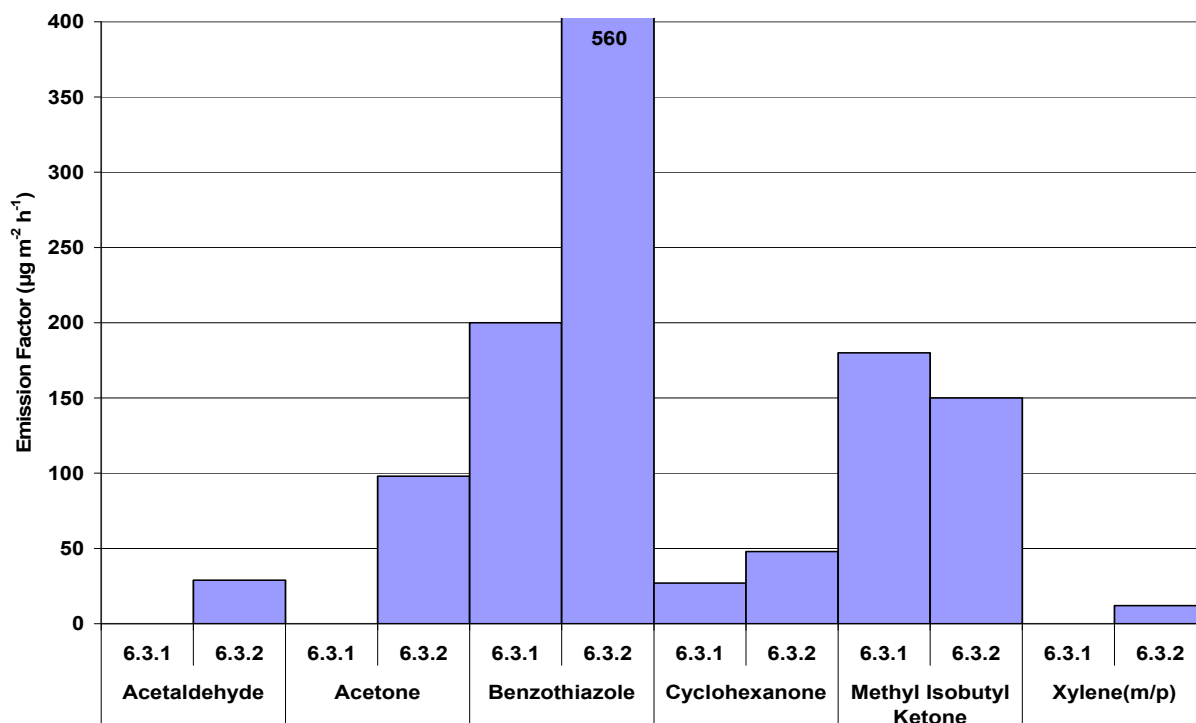


Figure 16 Emissions for two production lots of Product 6.3.Z.

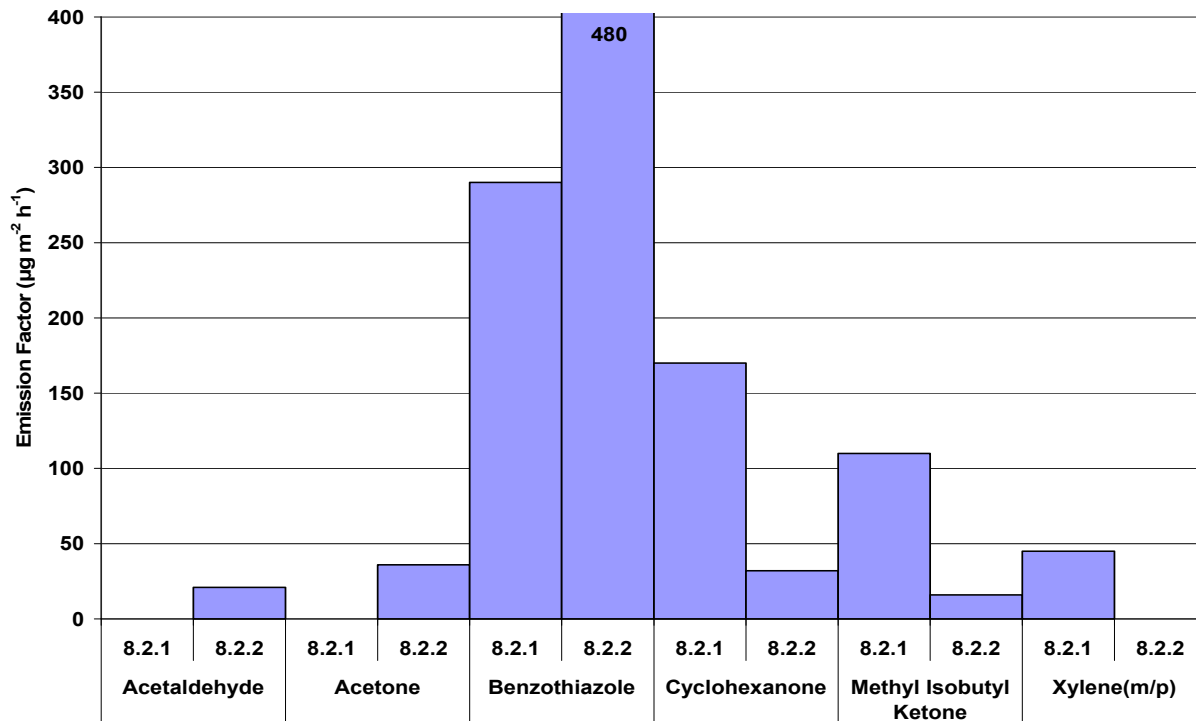


Figure 17 Emissions for two production lots of Product 8.2.Z.

Table 16 Selected chemical emission factors at 14 days for specimens for five sets of samples from multiple production lots.

Product ID	BHT	Carbon disulfide	Decanal	Ethylbenzene	Formaldehyde	Naphthalene	Phenol	Styrene	Toluene	Sum-VOC
	$\mu\text{g m}^{-2} \text{h}^{-1}$									
2.1.1		17		43	29				26	2040
2.1.2				38	28				30	2064
3.1.1		15								252
3.1.2		15								515
3.1.3	65		20	19		10	7			1100
3.1.4	68		19	12		8	7			898
3.2.1		15								350
3.2.2		15								565
6.3.1		16								599
6.3.2	150			12		8	7			1530
8.2.1			140	10				39	1200	2420
8.2.2					17					602

Figure 16 shows the VOC emissions for the Product 6.3.Z lot. In this set of lot replicates, minor emissions of carbon disulfide were found for Product 6.3.1 only, while acetaldehyde, acetone, and BHT were only released by Product 6.3.2.

Emissions from Product 8.2.Z lot are shown in Figure 17. Many chemicals were detected in Product 8.2.1 that were absent (below detection) in Product 8.2.2; notably styrene and toluene were found at levels near exposure guideline times for the former, but not in the latter. The SumVOC for Product 8.2.1 was more than 4x greater than emitted from Product 8.2.2.

The results of this limited study demonstrated that TDR product emissions were largely consistent from production lot-to-lot for the major emission components. However, many chemicals released in low amounts, including chemicals of concern such as toluene, styrene, benzene, formaldehyde, and acetaldehyde, were sometimes absent in one lot but found in another lot. Because the emission of VOCs from products can occur relatively rapidly after production, it is possible that the handling between manufacturing and receipt at the laboratory may contribute to some of the observed disparities.

VOC Release of TDR Flooring in Longer Periods

Prior emissions testing in this laboratory relied on a standardized screening protocol that included a 10-day conditioning period and measuring emissions at 14 days used in the BMES study. In order to ascertain VOC emissions over a longer time period for the current study, protocols were developed to extend the test period to 90 days. An additional goal is to characterize the variability in these products and the reliability of emission screening.

The VOCs emissions from rubber products and building materials have been successfully simulated by power-law curve (Zhang et al., 1999). In this study, for most products, the emission factors of most VOCs were below detection limits ($10 \mu\text{g m}^{-2} \text{h}^{-1}$) in the 60-day and 90-day samplings making fitting of the emission data with a power-law curve impractical.

The maximum emission factors at 28-day, 60-day and 90-day samplings are listed in Table 9. Using the maximum emission data and same model as the 14-day emission, the modeled room concentrations were below the cREL for VOCs with health effects such as xylenes, toluene, ethylbenzene, and naphthalene. This result suggested that the VOCs emission of TDR flooring products could decline to a safe level after a period of 90 days, although it may be because these compounds were largely present near the surface, and were depleted after a shorter period than the more substantial compounds, such as benzothiazole, methyl isobutyl ketone, and cyclohexone.

For some samples, the release of chemicals during 90 days should be roughly constant. VOCs such as methyl isobutyl ketone and cyclohexanone are largely used in the manufacturing process, so their emission changes display similar trend as benzothiazole. For many products, there was “no-consistent-trend” over time for the major VOC emitters. That is, emission rates sometimes decreased and subsequently increased with time, or vice versa. Considering benzothiazole as an example, we examined the effects of product properties (e.g., product thickness, product type and product composition) on the emission change. However, we did not observe a pattern between emissions and product characteristics. Since benzothiazole is used as vulcanization accelerators in tire rubber, the possible explanation is that most products are a substantial source of benzothiazole.

However, the more volatile compounds more often diminish, sometimes to *de minimus* levels, after 90 days. The benzene and carbon disulfide containing products are used in numerous steps during the production of the rubber and tires. However, due to the volatility of benzene and carbon disulfide, the release of these chemicals is fairly fast. The decay of the emission seems to occur in a short period. After 90 days conditioning, most of the benzene emission is below detection limit (see Table 17).

Table 17 Emission factors for selected chemicals from rubber flooring products for 14-d and longer testing periods.

Product ID	Rubber Size Use			Day	Benzene	Carbon disulfide	Ethylbenzene	Formaldehyde	Naphthalene	Toluene	Xylene(m/p)	Benzothiazole	Sum-VOC
					Emission Factor ($\mu\text{g m}^{-2} \text{h}^{-1}$)								
2.1.1	TDR	60	E	14	-	17	43	29	-	26	110	340	2,040
				28	-	4	19		240	7	-	140	1,038
				60	-	-	3	6	66	-	12	73	360
				90	-	-	-	7	63	-	8	160	470
2.1.2	TDR	60	E	14	-	-	38	28	-	30	100	350	2,064
				28	-	4	15		180	6	33	110	772
				60	-	4	-	3	72	-	6	20	240
				90	-	4	-	4	80	-	4	60	304
6.2.1	TDR	3	I	14	-	-	75	16	10	-	76	-	1,770
				28	-	-	-	4	18	-	-	-	127
				60	missing								
				90	-	-	3	-	51	2	3	-	302
6.4.1	NR	10	I	14	-	270	-	-	-	9	-	1,200	1,610
				28	-	45	-	3	7	4	-	460	604
				60	-	5	-		16	3	-	230	304
				90	-	-	-	-	10	1	-	120	184
7.1.1	TDR	10	I	14	56	19	-	-	-	29	150	880	2,051
				28	9	4	-	-	21	4	39	270	480
				60	13	5	-	-	23	4	42	310	569
				90	4	4	-	-	14	-	28	200	335
7.3.1	TDR	3	U	14	11	-	8	-	-	120	280	86	1,267
				28	-	3	-	-	-	-	10	160	216
				60	-	-	2	-	-	-	56	280	390
				90	-	-	-	-	-	-	1	160	174
8.2.1	TDR	10	I	14	-	-	10	-	-	1,200	45	290	2,420
				28	-	-	-	-	-	-	-	150	167
				60	missing								
				90	-	-	-	-	-	-	-	130	138

NOTES: Products with highest 14-d EF of selected chemicals; “-” means below LOQ;

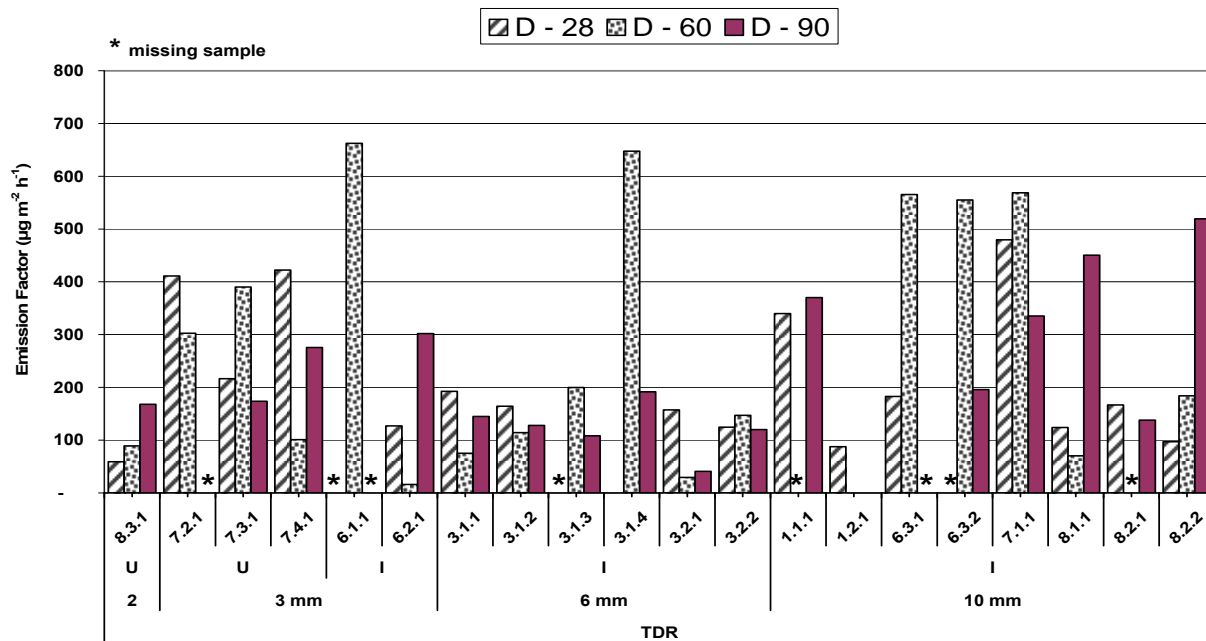


Figure 18 Chemical emission rates (SumVOC) at 28, 60, and 90 days for TDR (interior) flooring samples

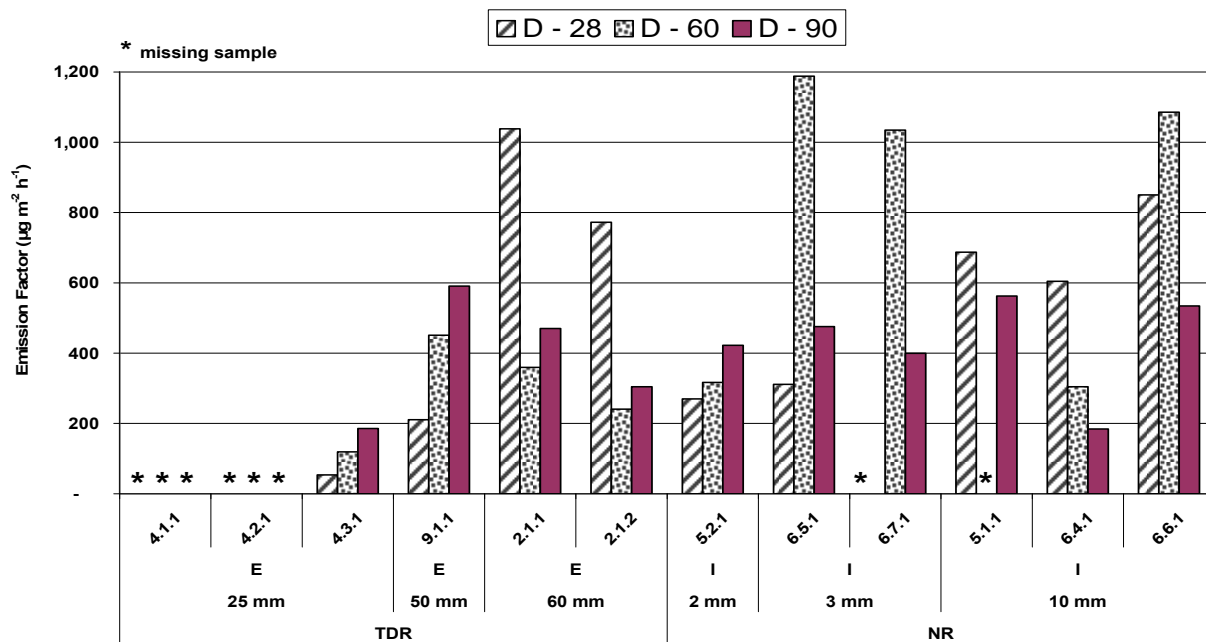


Figure 19 Chemical emission rates (SumVOC) at 28, 60, and 90 days for TDR (exterior) and NR flooring samples.

Effect of Q/A Ratio on Emission Factors of TDR Flooring

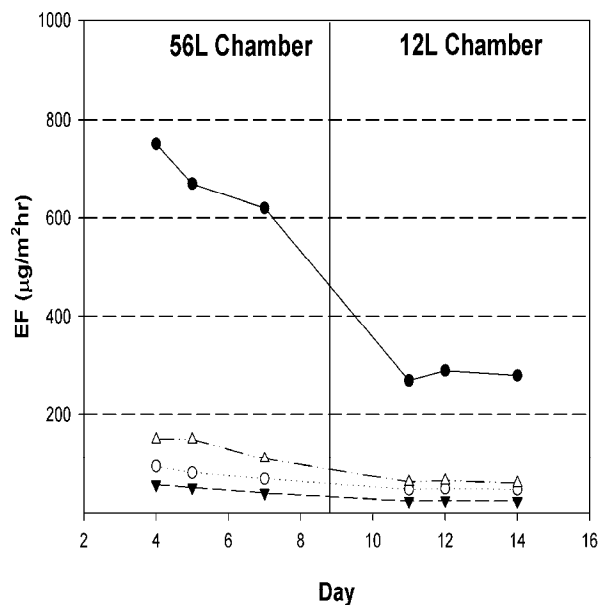
Studies found that the release of chemicals from dry building materials are based on two fundamental processes: the diffusion within the material as the result of concentration, pressure, or temperature gradients; and surface emission between the material and the overlying air as a consequence of evaporation, convection, and diffusion (Huang et al., 2002). The mass transfer within the material is mostly determined by the physical properties of the material and its manufacturing process while the test protocol set the conditions, e.g., temperature and air flow rate-to-surface area ratio or Q/A.

The Q/A ratio is defined as the ratio of airflow through the chamber to sample surface area (ASTM D6007). The Q/A ratio affects the VOC concentration in the overlying air, thus it affects the emission factor of VOCs in the test specimen. At a lower Q for the same A, chamber concentrations increase, which somewhat *suppress* emission factors. The higher air concentrations push back against the *emission force* at the surface. When the emission force at the surface is relatively large, i.e., fresh or wet products, then this effect can be negligible. The maximum effect would be exhibited for products where transport is *diffusion limited* at the surface. Then, the reduction in emission factors could be as high as the ratio of chamber Q/As, in this case the ratio of chamber volumes ($V_B/V_C \sim 56/12 \sim 4.7$).

In our sub-study, the same air exchange rate and surface area of specimen were used for tests conducted in two different size chambers, one 56 L (Chamber B), the other 12 L (Chamber C). For the 56 L chamber test, the air flow was controlled at 933 cc min^{-1} while 200 cc min^{-1} was used for the 12 L chamber testing. The Q/A ratio is 4.7 times higher for sampling in the 56L chamber compared to the one in 12 L chamber. Therefore, the same specimen had higher emission factors when placed in the 56L chamber compared to the 12L chamber.

Figure 20 shows significant differences of various VOCs' emission factors after the same specimen was tested in one chamber and then retested in the other. It demonstrates how important Q/A can be in controlling the VOCs emissions of TDR flooring. It needs to be specified in product assessments at levels appropriate to building practice, and considered when comparing emission guidelines defined in different methods of assessment. At the time the TDR study was conducted, this issue was not fully appreciated. Thus, the data from the small chamber study (11-day, 12-day, and 14-day) cannot be directly compared to that from the large chamber tests (28-day, 60-day, and 90-day) since they have different Q/A ratios. However, each test is valid on its own. At best, one may apply a correction for the emission factor effect between 1~4.7 with the caveats that (a) the effect will be different for different compounds; and (b) the effect will change (generally increase) over time, as chemicals in the surface layer are depleted.

Product 7.2.1



Product 6.3.2

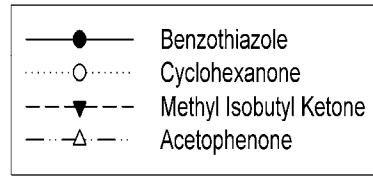
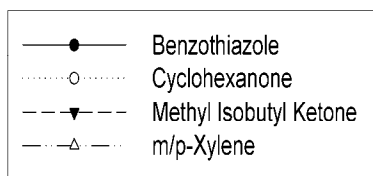
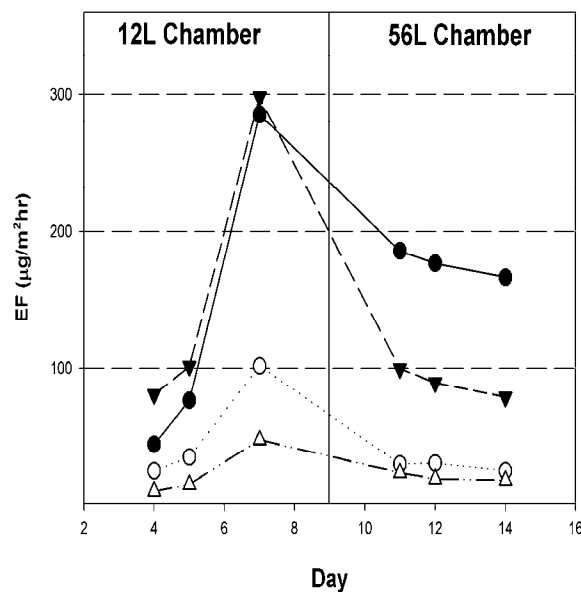
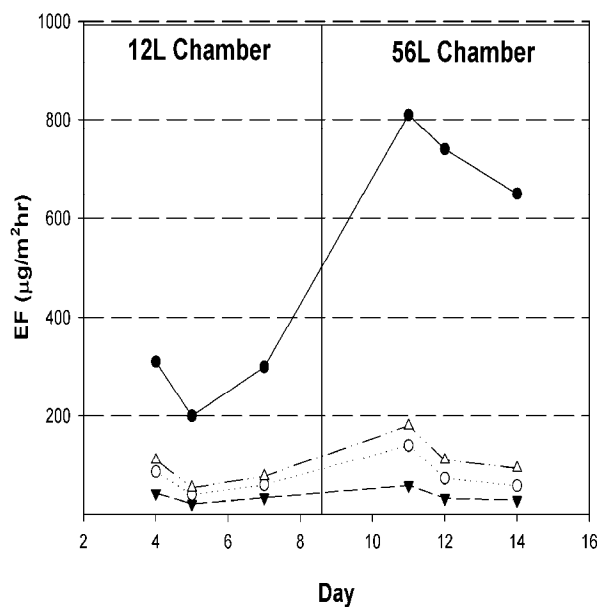
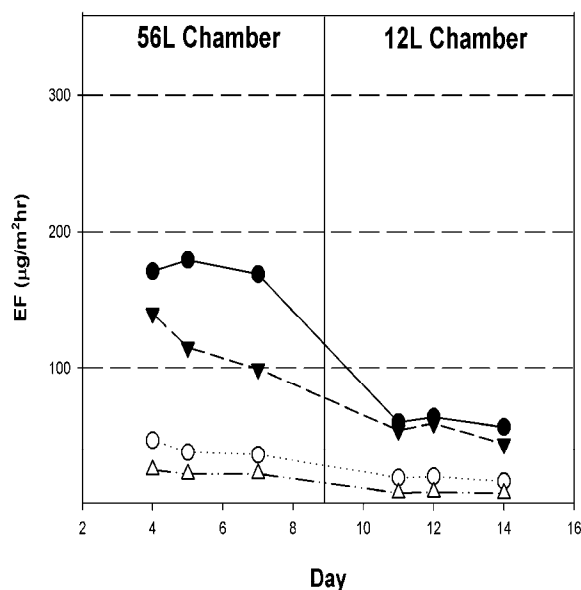


Figure 20 Comparison of emission factors for samples tested simultaneously in 56 L and 12 L chambers

Exposures to Chemicals of Concerns

Tire-derived flooring emits a wide range of volatile organic chemicals. These chemicals can cause an array of health effects. These health effects would likely occur at higher concentrations than the modeled indoor concentrations of chemicals emitted from tire-derived flooring alone in this study. However, many of these chemicals can cause eye, nose, throat, and lung irritation. The cumulative impacts of exposure to multiple chemicals may cause irritation, even if any one of the chemicals is below a threshold where irritation is known to occur. Quantifying the cumulative irritation impacts from an array of chemicals is difficult with the tools that are now available. Tire-derived flooring is also one of many products that may be off-gassing such chemicals, particularly in a new building. Therefore, the manufacturers of these products may want to consider ways to reduce the overall amounts of volatile organic solvents used in manufacturing of interior products. Storage conditions that promote off-gassing, and allowing for a period of time for products off-gassing prior to installation, could also be useful. Flushing of the building with outside air after installation of the product could also remove VOCs from indoor environments.

Benzene is a known carcinogen, and the modeled air concentrations for 12-day samples in some products exceed the Chronic Reference Exposure Level (cREL). Clearly, eliminating benzene from the manufacturing process is recommended, if the product is to be used indoors. Benzene does not have any unique solvent properties that would make it essential to the manufacturing process of TDR products, to our knowledge. Toluene and xylenes, for example, have similar solvent properties to benzene. Small amounts of benzene could occur as a contaminant in technical or industrial grade solvents used in the manufacturing process, but the results of this study indicate significant amounts from some other source.

The benzene cREL is intended to protect against lifetime exposure and exposure to benzene from tire-derived flooring would be expected to decline below the level of the cREL within a relatively short time period after installation. The cancer risk from exposure during the period of off-gassing is not likely to be significant in terms of typical total benzene lifetime exposure from other sources. However, positive steps to eliminate benzene from the manufacturing process would be prudent because (1) benzene contamination in other batches of technical or industrial solvents could be greater (2) the margin of safety for the benzene cREL is low because the basis is a human study (3) the adverse health effects of low levels of benzene could be compounded by combination with other volatile organic chemicals such as toluene. Exposures to workers installing the product could be of concern because the exposures would be both high and repeated. It should be noted that worker health standards for chemical exposure are different and higher than public health standards.

Modeled concentrations of carbon disulfide are significantly below the cREL, thus health impacts would not be expected from this level of modeled exposure. Carbon disulfide emissions could be greater in other batches of TDR flooring. At higher concentrations, carbon disulfide could present significant hazards during the manufacturing process. While carbon disulfide is not known to be a carcinogenic chemical, it would be prudent to use a less toxic solvent if this is possible. Public concern over the presence of this chemical could be a factor even if the modeled exposures are below health standards.

Comparison of Emissions of Current Study with BMES

Our previous study of material emissions (BMES) reported emission measurements for a variety of flooring materials, including TDR and new rubber flooring products similar to those tested in the current study. Table 18 compares results among the different types of flooring products (i.e., carpet, non-rubber flooring, and rubber-based flooring). The results shown are for the maximum 14-day emission factors for each flooring type. The alternative or “Alt” designation refers to products with higher recycled material content, compared to standard or “Std” products tested in the BMES. In general, the BMES found no notable differences between “Alt” and “Std” carpet or non-rubber flooring products with respect to VOC emissions.

Table 18 Comparison of emissions for selected chemicals from various flooring products tested in the Current Study and BMES.

	Acetaldehyde	Acetophenone	Benzene	Benzothiazole	BHT	Carbon disulfide	Ethylbenzene	Naphthalene	Toluene	Xylene (m/p)	Xylene (o)
	Max Emission Factor (µg m ⁻² h ⁻¹)										
CURRENT STUDY											
TDR – interior	38	200	56	880	150	19	75	10	1200	330	13
TDR – exterior	47	*	*	610	*	17	780	410	1900	2900	1600
New rubber (NR)	26	*	*	3900	1500	270	*	*	88	*	*
BMES (2003)											
Resilient rubber – Alt (TDR)	*	2300	*	540	-	-	7	14	22	15	20
Resilient rubber – Std (NR)	*	18	*	590	-	-	*	28	*	*	*
Resilient non-rubber – Alt	49	*	6	*	-	-	6	7	12	6	6
Resilient non-rubber – Std	15	*	6	*	-	-	6	14	9	*	5
Carpet – Alt	37	*	7	*	-	-	11	59	41	15	10
Carpet – Std	11	*	7	*	-	-	11	50	10	8	12

NOTE: * denotes below reportable limit in Current Study and BMES
 - denotes analyte was not measured in BMES report.

More chemicals were reported in the emission of rubber flooring products in the current study than in the BMES testing. The current study identified emissions of benzene, xylene (m/p), xylene (o), ethylbenzene from TDR flooring products. The BMES study found that one TDR flooring product had very high emissions of acetophenone compared to the current study results (2300 versus 200 $\mu\text{g m}^{-2} \text{h}^{-1}$).

Benzothiazole was emitted at substantial amounts by both TDR and NR flooring products, while absent in all the carpet and non-rubber resilient flooring tested. It remains a consistent marker for rubber flooring emissions of any type, with new rubber flooring having the highest emissions. Acetophenone was also notably absent from carpet and non-rubber flooring tested in the BMES, while emitted at high rates for TDR and much lower rates for NR.

Ethylbenzene, toluene and the xylenes were all emitted highest from TDR products, while BHT was released more from new rubber products. All flooring products released acetaldehyde and naphthalene, except new rubber flooring products tested in the current study. TDR flooring designated for *exterior-use* was generally found to release more chemicals with higher emission factors than *interior* (TDR and NR) flooring. An exception was carbon disulfide, which was found in both TDR and NR (17 samples) in the current study.

Summary and Recommendations

In conducting the current study, we successfully acquired a wide range of TDR and NR flooring products to learn about product emission factors of VOCs. We also acquired replicate samples manufactured in different times to see how rates varied for different production lots. In this study, we extended our 14-day protocol (i.e., Section 01350) to include long-term conditioning and chemical emission testing at 28 days, 60 days, and 90 days.

Results show that some TDR flooring products still emit substantial VOC chemicals, and their release is not uniform among the different products. Three compounds (benzothiazole, methyl isobutyl ketone, and cyclohexanone) were emitted at substantial rates for most flooring products tested. For most products, emissions for these compounds were 75 percent or more of TVOCs released. TVOC emission factors were generally high, leading to potential room concentrations from 500 to several thousand $\mu\text{g m}^{-3}$.

Several chemicals of concern (listed by OEHHA with Chronic Reference Exposure Levels or cRELs) were emitted at measurable rates. Xylenes and acetaldehyde were found in a range of products, while benzene and carbon disulfide were found at potential hazardous levels in just one or two samples. These contaminants seem to be due to minor constituents in the manufacturing process, since they were sometimes found in one production lot and not another. Other chemicals of health concern were absent or emitted at low rates in most products. However, some of the identified chemicals do not yet have health-based standards making their health impacts difficult to assess.

For the rubber flooring products acquired from different production lots, major emission constituents were mostly consistent. In a small subset of products (notably an interior/exterior TDR paver), a large amount of one or two unidentified compounds were emitted. We had limited success in identifying previously unresolved GC/MS peaks; we were able to determine many of these compounds by their chemical classes.

The long-term testing of TDR products showed off-gassing chemicals had different emission factors over time. Some rates decreased rapidly (after 14 days), while others dropped slowly or even increased to higher levels. We suspect this is related to the physical composition or other factors in the product, as well as the compound. The decline of benzothiazole, methyl isobutyl ketone, and cyclohexanone emission factors (as well as TVOCs) were slower than for the more volatile minor constituents, e.g., acetone, acetaldehyde, and benzene. In terms of *long-term* chemical exposures to room occupants, we found these minor constituents were largely depleted after 14 days. However, the major TVOC constituents persist, and as much as 25 percent of long-term exposures can remain after the 14-day flush-out period.

Interior Use of TDR Flooring Products

Based on concerns about the impact on indoor air quality of the myriad of constituents emitted, the authors of the 2003 BMES report cautioned that tire-derived rubber-based products should not be promoted for wide use in most indoor environments until further studies are done. The current study results show that TDR flooring products still emit a myriad VOC chemicals, but the release of *chemicals of concern* are not uniformly high among the different products. In addition, the long-term testing of TDR flooring products showed emission factors for these chemicals decrease fairly rapidly.

The IAQ Standard Practice under Section 01350 provide testing standards for building products, and these can be adapted to help screen TDR flooring products to rule out chemicals of concern, as well as products with high VOC emission rates. Chemicals such as benzene and carbon disulfide *should not* be in TDR flooring products, so emission test data will help manufacturers eliminate them (e.g., by specifying a higher quality of solvents). Because TDR and NR flooring products do occasionally emit large amounts of chemicals that are not readily identified or have no established health-based exposure limits, special consideration would need to be given to their “total” VOC emission factors.

The new study findings suggest that, despite occasional “high emitters,” not all TDR flooring products need to be ruled out for indoor use. IAQ specifications often require a period of pre-occupancy *flush out* to ensure that VOC emissions will be within acceptable limits (e.g., *Section 01350* screening is based on the emissions after 14 days), and guidelines such as *CHPS* and *LEED* include credits or prerequisites for a seven-day pre-occupancy *flush out*. Based on their initially high emission factors and relatively slow drop (*cf.* at 14 days), we would additionally recommend that IAQ specifications call for longer pre-occupancy *flush out* (or off-site pre-conditioning) when TDR flooring products are used indoors. Data for the current study suggest that most chemical emissions are substantially reduced after 90 days.

Need for Future Studies

While the BMES provided a broad panorama of VOC exposures associated with building products by reporting chemical emissions at 14 days from many types of materials, the current study attempted to burrow deeper into the complex issues affecting the performance of one class of material. Principally, we investigated the nature of VOCs released by the different types of rubber flooring, and extended testing over a longer time period.

At the same time, many variables and concerns relating to TDR flooring were beyond the scope of the current project. Several key questions remain to be addressed to further the understanding of potential health risks for building occupants where TDR (and NR) products are used. Furthermore, there is an opportunity to work with manufacturers to better understand aspects of production that influence contaminant emissions. Below are several areas of interest for future study:

1. **Chemical emissions associated with adhesives in assemblies, top-coats, finishes and cleaning agents.** There are many products that are used in association with any flooring option, and it is important to understand the ancillary contributions to indoor exposures by the use of adhesives, top-coats, and finishes. Furthermore, required maintenance lead to new sources of chemicals being added over the life of the product, and these may contribute more than the original product over its lifetime.
2. **Characterize TDR flooring product parameters (e.g., feedstock source and surface physics) to estimate their impact on chemical emissions.** Research physical characteristics that may impact the off-gassing of chemicals, such as surface porosity and thermal stability. In addition, the impact of feedstock source used in flooring should be investigated to assess product emissions with respect to their source and physical parameters.
3. **Fate of semi-VOCs emanating from building products.** With the primary focus on VOC emissions, little research has been conducted on the exposures to semi-VOCs. It is likely that emissions of these products, such as phthalates, would be small, but persistent. There would likely be an accumulation of semi-VOCs in foams and house dust.

4. **Investigation of heavy metals released TDR flooring products.** California Integrated Waste Management Board (2007) assessed the heavy metals (lead, cadmium, zinc) released by recycled tires, which estimated a potential (modest) risk from chronic hand-to-mouth contact with playground surfaces made of TDR. Nonetheless, as there is little available data on the magnitude of metal content (or its mobility) in TDR *flooring*, we recommend that CalRecycle assess the potential for heavy metal exposure specifically from flooring (especially for small children) in future research.
5. **Long-term impacts on emissions from material wear, damage, and chemical degradation.** We looked at TDR and NR flooring products under “best case” conditions—newly manufactured, in a clean environment, prior to its use. While we observed emissions decline for chemicals contained in the rubber, we might expect to see some emissions rise because of the impact of material wear, overt damage (e.g., rips), and chemical degradation by oxidants and ultraviolet (UV) light.
6. **Field evaluation of TDR and NR flooring product emissions.** Little has been reported on VOC emissions from TDR and NR flooring in actual indoor environments, such as classrooms, offices, or residences. Field study would allow evaluation of the impact of use—abrasion, moisture, cleaning, UV and oxidants—on VOC emissions. In addition, it is known that tire wear releases particulate matter made of rubber and organic carbon. We anticipate that activities such as walking and cleaning will cause the release and re-suspension of fine particles from TDR flooring. Hence, a study should evaluate real-world exposures to fine particles as well as to VOCs where TDR and NR flooring is used.
7. **Pilot a quality assurance program for TDR flooring manufacturers.** In the BMES and current study, manufacturers of TDR flooring cooperated with CDHS in providing samples and information about their manufacturing. They appear committed to developing their products to new markets, and they are concerned about health risks and customer acceptance. There is the opportunity to establish a “reformulation testing sequence” for repeated testing for manufacturers willing to provide proprietary formulation information on their product. This collaboration would both improve individual product(s) and our understanding the manufacturing processes that affect chemical off-gassing.
8. **Evaluate allowable limits for TVOC emissions for rubber flooring to be used indoors.** TVOC limits have largely fallen out of favor in the newer IAQ specifications, which focus chiefly on health-based standards for individual chemicals, such as the cRELs developed by OEHHA. However, high TVOC emissions, if not a direct health risk per OEHHA limits, represent a “red flag” for products that will cause *uncomfortable* (if not *unacceptable*) indoor air quality. Those products with the highest TVOC emissions often have strong odors which persist for extended periods following installation. TVOC emission limits, such as used in the *Greenguard Certification* (500 µg/m³), may serve to identify products that have not addressed the IAQ impact of chemical contaminants and strong or noxious odors. Hence, it may be appropriate to establish an allowable limit for TVOC emissions for rubber flooring to be used indoors, as a supplement to the CDPH Section 01350 VOC screening and acceptance criteria.

Abbreviations and Acronyms

A _c	exposed area of the material in the chamber [m ²]
ACH	air change rate [h ⁻¹]
amu	atomic mass units
A _t	exposure area of the material in the room [m ²]
b ₀	initial emission factor [μgm ⁻² ·h ⁻¹]
b ₁	decay rate [day ⁻¹]
BMES	Building Material Emissions Study; see CA DHS (2003) in References
C	chamber concentration of the compound [μg m ⁻³]
C _m	modeled concentration of the compound [μg m ⁻³]
C _o	background chamber concentration of the compound, generally zero [μg m ⁻³]
CDHS/CDPH	California Department of Health Services / Department of Public Health
CHPS	Collaborative for High Performance Schools
CIWMB	California Integrated Waste Management Board (now known as CalRecycle)
DNPH	2,4-dinitrophenylhydrazine [carbonyl sampling cartridge media]
EF	emission factor of the compound from the material [μg m ⁻² h ⁻¹]
GC/MS	gas chromatography/mass spectroscopy instrument
ISTEA	Federal Intermodal Surface Transportation Efficiency Act
K	conversion factor for a given exposure scenario
LEED	U.S. Green Building Council's <i>Leadership in Energy and Environmental Design</i>
LOQ	limit of quantitation
OEHAA	California Office of Environmental Health Hazard Assessment
Q _c	chamber airflow rate [m ³ h ⁻¹]
REL	Reference Exposure Level
RH	relative humidity [%]
R _t	retention time
t	age of the tested product [day]
T	temperature [°C]
TDR	Tire-Derived Rubber
VOCs	volatile organic compounds
V _R	room volume where material will be installed [m ³]

References and Bibliography

Birkholz D, Belton K, and Guidotti T, 2003. Toxicological evaluation for the hazard assessment of tire crumb for use in public playgrounds. *J. Air & Waste Mgmt. Assoc.* 53: 903-907.

California Department of Health Services, 2003. *Building Materials Emission Study*. Report to the California Integrated Waste Management Board; Public Health Institute Contract IWM-C0042. Indoor Air Quality Section, Richmond, CA 94804. Available online: <http://www.calrecycle.ca.gov/GreenBuilding/Specs/Section01350/METStudy.htm>

California Department of Health Services, 2004. *Standard Practice for the Testing of Volatile Organic Emissions from Various Sources using Small-Scale Environmental Chambers*. Indoor Air Quality Section, Richmond, CA 94804. Available online: [www.cal-iaq.org/VOC/](http://www.calrecycle.ca.gov/GreenBuilding/Specs/Section01350/) and <http://www.calrecycle.ca.gov/GreenBuilding/Specs/Section01350/>.

California Integrated Waste Management Board, 2004. *Evaluation of Waste Tire Devulcanization Technologies*. Contractor Report produced by CalRecovery, Inc. Publication Number: 622-04-008. December 2004, 99 pp. <http://www.calrecycle.ca.gov/Publications/Tires/62204008.pdf>

California Integrated Waste Management Board, 2007a. *California Waste Tire Generation, Markets, and Disposal: 2006 Staff Report*. Publication Number: 620-08-001. Prepared by CSUS in June 2007, 7 pp. <http://www.calrecycle.ca.gov/Publications/Tires/62208001.pdf>

California Integrated Waste Management Board, 2007b. *Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products*. Contractor's Report produced by OEHHHA. CIWMB Publication Number: 622-06-013. January 2007, 147 pp. <http://www.calrecycle.ca.gov/Publications/Tires/62206013.pdf>

California Integrated Waste Management Board, 2009. *Five-Year Plan for the Waste Tire Recycling Management Program* (5th Edition Covering Fiscal Years 2009/10–2013/14) Report to the Legislature. Publication #IWMB-2009-011, July 1, 2009. 90 pp. <http://www.calrecycle.ca.gov/Publications/Tires/2009011.pdf>

Chang F, Lin T, Huang C, Chao H, Chang T, and Lu C, 1999. Emission characteristics of VOCs from athletic tracks. *J. Hazardous Materials* 70: 1-20.

Gunter M, undated. *The Environmental Suitability of Scrap Tire Chips in a Saturated Environmental*. University of Wisconsin as cited in *The Environmental Impact of EcoFlex Paving Systems*, EcoFlex, Australia.

Hartwell S, Jordahl D, Dawson C and Ives A, 1998. "Toxicity of scrap tire leachates in estuarine salinities: Are tires acceptable for artificial reefs?" *Transactions American Fisheries Society*, Vol.127, pp. 796-806.

Kumata H, Yamada J, Masuda K, et al., 2002. Benzothiazolamines as tire-derived molecular markers: Sorptive behavior in street runoff and application to source apportioning. *Environ. Sci. Technol.* 36: 702-708.

Market Research, 2000. Market Profile: Floor Coverings Industry, July, SB370 ISBN 1-56241-681-2. Available online at <http://www.MarketResearch.com>

Myhre M and MacKillop, DA, 2002. Rubber recycling. *Rubber Chemistry and Technology*, 75: 429-474.

Office of Environmental Health Hazard Assessment, 2009. *California Air Toxics Hot Spots Program*, http://oehha.ca.gov/air/hot_spots/index.html. Refer to California Health and Safety Code Section 44360(b)(2).

Reddy C and Quinn J, 1997. "Environmental chemistry of benzothiazoles derived from rubber." *Environ. Sci. Technol.* 31: 2847-2853.

Sullivan J, Van Ert M and Lewis R, 1992. Chemical hazards in the tire and rubber manufacturing industry. In: Hazardous Materials Toxicology, Clinical Principles of Environmental Health (Sullivan, J. and Krieger, G, Eds.). Williams and Wilkins, Baltimore, pp. 516-532.

U.S. EPA , 1995. *Manufacturing from Recyclables 24 Case Studies of Successful Recycling Enterprises*, Report No. EPA-530-R95-001; Washington D.C.

US EPA, 2003. Toxicological review of Methyl Isobutyl Ketone. U.S. Environmental Protection Agency, Washington D.C.

U.S. EPA, 2006. *Management of Scrap Tires: Basic Information*. Office of Solid Waste website: <http://www.epa.gov/epaoswer/non-hw/muncpl/tires/basic.htm>, last updated Feb. 22, 2006.

U.S. RMA, 2009. *Scrap Tire Markets in the United States, 9th Biennial Report*, Rubber Manufacturers Association, Washington D.C, May 2009. Available online at http://www.rma.org/scrap_tires.

Watts et al., 1998. Airborne exposures to PAH and PM_{2.5} particles for road paving workers applying conventional asphalt and crumb rubber modified asphalt. *J. Expo. Anal. Environ. Epidemiol.* Apr-Jun;8(2):213-29.

Appendix A. Correspondences to Rubber Flooring Manufacturers

- A1. June 13, 2005
- A2. Sept. 19, 2005
- A3. List of Rubber Flooring Manufacturers

This page intentionally left blank.



California Integrated Waste Management Board

Rosario Marin, Chair

1001 I Street • Sacramento, California 95814 • (916) 341-6000

Mailing Address: P. O. Box 4025, Sacramento, CA 95812-4025

www.ciwmb.ca.gov



Alan C. Lloyd, Ph.D.
Secretary for
Environmental Protection

Arnold Schwarzenegger
Governor

June 13, 2005

Dear Tire-derived Rubber Product Manufacturer:

The California Integrated Waste Management Board (Board) recently commissioned a study to better understand the chemical emissions of tire-derived resilient flooring products and their impact on indoor air quality. The Board promotes the use of recycled content building materials as a means to develop sustainable building markets for materials diverted from landfills. Recent studies suggest that before such products can be promoted for widespread use indoors, more testing and refinement of these products may be needed. Hence, the Board is interested in working with manufacturers to this effect.

We are writing to you because your company is identified as producing recycled tire products that can be used indoors. We are asking for your assistance with this study, which will provide valuable information to manufacturers of tire-derived flooring products and help to protect public health. The larger goal of this study is to promote the use of sustainable building materials that ensure a healthy indoor environment. In particular, the Board would like to ensure that tire-derived resilient flooring are formulated as low-emitting products that can be promoted for wider usage indoors, thus increasing their market share and facilitating the greater recycling of tires.

In the study, chemical emission rates will be measured on a subset of tire-derived flooring products, under direction of the Department of Health Services-Indoor Air Quality Program. The laboratory procedures for handling and testing materials are part of California's Department of Health Services Standard Practice for indoor air quality testing that can be found on their web site: www.dhs.ca.gov/iaq/VOCS/Practice.htm. Long-term (weeks to months) chemical emissions testing will also be conducted to determine how emissions change over time.

The Public Health Institute (PHI), an independent, nonprofit organization, will store product identity data – *all identifying information collected for this study will be kept confidential*. Manufacturers will be given laboratory results for samples they provide, if they wish, as well as the ID for their samples, but public reports will include only anonymous sample ID numbers or grouped results. This approach was used successfully in our prior study on a wider range of products. The *Building Materials Emissions Study* report is on-line at: www.ciwmb.ca.gov/GreenBuilding/Specs/Section01350/METStudy.htm.

California Environmental Protection Agency

 Printed on Recycled Paper

The energy challenge facing California is real. Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs, see our Web site at <http://www.ciwmb.ca.gov>

June 13, 2005

Page 2

We are looking for the following information from companies that manufacture tire-derived flooring products:

- Information on your company's flooring products made from tire-derived materials.
- Source and recycled content percentage of California tires used.
- Emission testing data, if available; for example, data supplied for the CHPS' *Low-Emitting Materials Table* at www.chps.net/manual/lem_overvw.htm. *Note: propriety data will be kept confidential by PHI.*
- Name and phone number or email address for person we may contact to request *factory-direct* product samples.

Ms. Paola Taranta, PHI Research Associate, will be contacting your office to request this information and discuss questions you may have; she can be reached at 510-620-2856.

Information and updates on the study progress will be available on the project web site at: www.cal-iaq.org/TIRE.

If you have immediate concerns or questions, please feel free to contact me at (916) 341-6472 or borr@ciwmb.ca.gov. You can also contact the study's principal investigator, Dr. Jed Waldman, Chief of the Indoor Air Quality Program at (510) 620-2864 or jwaldman@dhs.ca.gov. I look forward to working with you on this study that will provide valuable data to manufacturers and promote a healthy indoor environment.

Sincerely,

A handwritten signature in black ink that reads "William R. Orr". The signature is fluid and cursive, with the first name "William" being the most prominent part.

William R. Orr, Manager
Recycling Technologies Branch

cc Dr. Jed Waldman, Chief
Department of Health Services Indoor Air Quality Program

Paola Taranta, Research Associate
Public Health Institute

Appendix A3. List of Manufacturers of Rubber and Recycled Rubber Products

	Company Name	City	State	Products Made
1	Ace Rubber Products, Inc.	Akron	OH	mats
2	Advanced Rubber Surfacing Products Inc.	Red Bluff	CA	mats
3	All About Play	Sacramento	CA	
4	American Floor Products Co.	Rockville	MD	flooring
5	Amorim Industrial Solutions	Trevor	WI	
6	Ashland Rubber Mats Co.	Ashland	OH	mats
7	Atlantic Rubber Products, Inc.	East Wareham	MA	
8	Atmosphere	Oklahoma City	OK	
	B.A.S. Recycling, Inc. - See Environmental Molding Concepts			
9	Baxter Rubber Co.	Fairfield	NJ	mats
10	Bay Area Tire Recycling			
11	Benyon Sports Flooring	Hunt Valley	MD	flooring
12	Burke Industries, Endura Products Division	San Jose	CA	flooring
13	Cactus Mat Manufacturing, Co.	El Monte	CA	mats
14	Carlisle Tire and Rubber Co.	Carlisle	PA	flooring
15	Connor Sport Court International	Arlington Heights	IL	
16	Degussa Building Systems	Shakopee	MN	adhesive
17	Dinoflex Manufacturing Ltd.	Salmon Arm	BC, CANADA	flooring
18	Dodge Regupol Inc.	Lancaster	PA	flooring
19	Durable Corporation	Norwalk	OH	flooring & other products
20	Earth Safe, Inc.	Marstons Mills	MA	
21	Environmental Molding Concepts / BAS Recycling	San Bernardino	CA	flooring
22	Everguard Products, Inc.	Amityville	NY	flooring
23	Expanko Cork Company, Inc.	Parkesburg	PA	flooring
24	Flexco - see Roppe	Tuscumbia	AL	
25	Freudenberg Building Systems, Inc / Nora Rubber Flooring	Lawrence	MA	flooring
26	Global Rubber West, Inc.	King of Prussia	PA	
27	Huffco Manufacturing, LLC	Stockton	CA	
28	Humane Manufacturing Co.	Baraboo	WI	
29	Interstate Mat and Rubber Co.	South Easton	MA	
30	Johnsonite Division of Duramax	Chagrin Falls	OH	flooring
31	Kellett Enterprises, Inc.	Greenville	SC	mats
32	Koneta, Inc	Wapakoneta	OH	mats
33	Koroseal Matting Products, Div. RJF International Corp.	Burlingame	CA	
34	Lancaster Colony / Pretty Products, Inc. / Rubber Queen	Coshocton	OH	mats

	Company Name	City	State	Products Made
35	Lock-tile / Evertile Flooring Co	Brooklyn	NY	
36	Ludlow Composites Corp.,	Fremont	OH	
37	Marathon Athletic Surfaces	Vancouver	BC, CANADA	
38	Mat Inc.	Stoughton	MA	flooring
39	Mitchell Rubber Products, Inc.	Mira Loma	CA	
40	No Fault Sport Group, LLC	Baton Rouge	LA	
41	North West Rubber Mats, LTD	Abbotsford	BC, CANADA	
42	Northeast Flooring Solutions	Salem	NH	
43	Northern Industries	Coventry	RI	flooring
44	Nova Process Technology, Inc.	Wausau	WI	flooring
45	NRI Industries, Inc.	Toronto	Ontario, CANADA	flooring, mats
46	Oregon Rubber Mat	Eugene	OR	mats
47	Pathway Surfaces	Baton Rouge	LA	
48	Pawling Corporation - Architectural Products Division	Wassaic	NY	
49	Pendley Group	Calhoun	GA	
50	Playground Unlimited			
51	Polymer Plastics Corp., Vitricon Div.	Hauppauge	NY	
52	PRF USA, Inc.	Carlstadt	NJ	
53	Profloor	Wyckoff	NJ	flooring
54	R.C. Musson Rubber Co	Akron	OH	mat
55	Rainbow Turf Products	Saint Cloud	FL	
56	RB Rubber Products	McMinnville	OR	flooring
57	RCA Rubber Co.	Akron	OH	
58	RCM International	Rome	GA	
59	Recovery Technologies Group	Guttenberg	NJ	
60	Redwood Rubber, LLC	Corte Madera	CA	crumb
61	Reifen Rubber Co., Inc.	Manheim	PA	flooring
62	Rephouse	Guelph	Ontario, CANADA	
63	Rhino Mats and Matting	Houston	TX	mats
64	Robertson Industries			
65	Roppe Corporation, USA	Fostoria	Ohio	
66	Royal Mat Inc.	Beauceville	Quebec CANADA	
67	Royal Rubber & Manufacturing Co	South Gate	CA	
68	Rubber Manufacturers Association	Washington	DC	
70	Rubber Products, Inc. -see Tuflex Rubber Flooring			

	Company Name	City	State	Products Made
71	Rydean Molded Products, Inc.	Banning	CA	
72	Safe Guard Surfacing Corp.	Sun Valley	CA	
73	Soft Ball Inc.	Bluffdale	Utah	flooring
74	Surface America	Williamsville	NY	flooring
75	Surface Technology, Inc.	Lancaster	PA	
76	Tire Distribution Systems Incorporated	Stockton	CA	buffings
77	Tuflex Rubber Flooring	Tampa	FL	
78	U.S. Mat and Rubber Corp.	Brockton	MA	mats
79	U.S. Rubber Sports Floor Systems	Riverside	CA	
80	U.S. Rubber Supply Co.	Brooklyn	NY	
81	Ultimate Systems	Delphos	OH	Flooring
82	Unity Surfacing Systems (Unity Creations)	Saugerties	NY	Flooring
83	Utah Tire Recyclers	Salt Lake City	UT	Buffings
84	Veplas Mfg. Ltd.	Salmon Arm	BC, CANADA	
85	Wearwell, Tennessee Mat Company Inc.	Nashville	TN	
86	West Coast Rubber Recycling, LLC	Gilroy	CA	drains and parking lot curbs
87	Yemm and Hart	Marquand	MO	



September 21, 2005

Dear «Contact_Name»:

The California Integrated Waste Management Board (Board) recently commissioned a research study to better understand the chemical emissions of tire-derived resilient flooring products and their impact on indoor air quality. The Board has ruled that such products should be tested further before being promoted for widespread use indoors. The Public Health Institute (PHI), an independent, nonprofit organization, and the State Department of Health Services Environmental Health Laboratory Branch are conducting this study.

We are contacting all tire-derived rubber flooring manufacturers in the United States regarding their flooring products that can be used indoors. We need your assistance with this study, which will in turn provide valuable information to manufacturers and help to protect public health. If you are interested in obtaining more information about the study, you can visit the project website at: www.cal-iaq.org/TIRE.

PHI will store product identity data – *all identifying information collected for this study will be kept confidential*. Manufacturers who participate in this study, will be given laboratory results for the samples they provide, if they wish, but public reports will include only anonymous sample ID numbers and grouped results.

At this point, we are looking for information about your manufacturing process. Please take a moment to fill out the enclosed survey. If you would prefer to fill out the survey electronically, the survey is also available at our website.

I will contact your office next week to answer any questions you may have about this request.

Sincerely,

Paola Taranta, Research Associate
Public Health Institute
510 620-2856
ptaranta@phi.org

Appendix B. Protocols for Material Emission Testing

Extended Laboratory Procedures, including:

- Instruction to Manufacturers for Submission of Product Specimens
- Tire-Derived Rubber Flooring Study Industry Survey
- Chain-of-Custody form
- TDRFS Sampling Data Sheet

This page intentionally left blank.

PHI/DHS TIRED-DERIVED RUBBER FLOORING STUDY

Extended Protocols for Material Emission Testing

FINAL

TABLE OF CONTENTS

[Introduction](#)

[Instructions to Manufactures](#)

[Specimen Selection](#)

[Specimen Preparation & Assemblies](#)

[Testing Facilities](#)

[Chemical Emission Testing](#)

[Figure & Tables](#)

[Attachments](#)

INTRODUCTION

The study design for the Tired-derived rubber flooring study is largely based the approach used in the *Building Material Emissions Study*^a. These have been expanded and formalized in the DHS' *Practice for Testing of VOCs from Building Materials Using Small Chambers*^b.

The *Practice* was developed for use when manufacturers submit flooring specimens for testing as part of product selection specifications. In this study, we will be soliciting manufacturers for their product specimens for research testing. Hence, we have identified some modifications of the specimen acquisition & handling elements. In addition, product testing will be extended past the standard 14-d period – up to a 90-d period – to determine longer-term exposures associated with indoor product applications. This document outlines the additions and modifications to our documented procedures.

INSTRUCTIONS TO MANUFACTURES

A letter from CIWMB was sent in June 2005 to all rubber flooring manufacturers identified by PHI staff. By mid-August, PHI staff will have contacted all companies to identify a point of contact for the study. Each company will be asked to complete a survey form on their products and production process (**Attachment A**) and (b) submit product specimens that are used indoors. A subset will be asked to submit crumb and/or buffing rubber used in manufacturing.

Specific requirements for submission of floor products were distilled from the *Practice* into a short instructional memo for manufacturers (**Attachment B**). The format changes “shall” to “should”. In addition, packing kits have been prepared for product submission. These contain heavy duty aluminum-foil sheets, plastic bags, bar-coded label sets, and chain-of-custody forms.

Our laboratory chain-of-custody form was customized for this project; it is identified as a “PHI” form (**Attachment C**).

^a www.ciwmb.ca.gov/GreenBuilding/Specs/Section01350/METStudy.htm

^b <http://www.dhs.ca.gov/iaq/VOCS/Practice.htm>

PHI/DHS Tire-Derived Rubber Flooring Study
Extended Protocols for Material Emission Testing

SPECIMEN SELECTION

The following criteria have been developed for selection of tire-derived rubber flooring products to be solicited among manufacturer willing to participate and submit dated product specimens:

- identified for interior use (including multi-purpose to heavy duty)
- used in a large surface area in the room
- among the biggest selling products for manufacturer
- manufactured with recycled California tires (desirable, but not required)
- poured-in-place products will be considered (if technically feasible)

A number of exemplary rubber flooring products (non-tire-derived) will be selected using the former three criteria. In the event that a product is identified as desirable and the manufacturer is not willing to submit a specimen, then the selected product may be acquired from a distributor or retailer.

SPECIMEN PREPARATION & ASSEMBLIES

Specimens will be tested as detailed in the DHS Standard Practice. Flooring will be tested as without adhesive or sealers. Screening tests (see below) will be used to identify chemicals emitted from the adhesives and sealers alone.

TESTING FACILITIES

The laboratory uses three kinds of small chambers (see **Figure 1**). Chambers will be wiped with methanol and air dried before & after each specimen is loaded. The small-chamber configurations are summarized in Table 1 and described below:

Chamber A. A set of 16½ l chambers (i.e., tin food-storage containers) will be used for material conditioning. Distinct products will be individually conditioned, although replicate samples may conditioned together. These will be used (a) for the initial (10-d) conditioning period, and (b) for the extended conditioning of specimens for the long-term tests (28-d, 60-d, 90-d, etc.). The clean air supply will be delivered at 1 air exchange per hour (AER=1/h), and it will be derived from laboratory (“house”) air which goes through a carbon filter (“C-trap”) or compressed air or nitrogen. The target RH will controlled using a mix of dry & humidified air flows, controlled with needle valves & rotometers to determine flow rates. The chambers will be operated within the conditioned laboratory space.

Chamber B. Two 56 l stainless-steel chambers will be used for the standard (“Section 01350”) 4-d emission tests. i.e., specimens will be loaded into these chambers at the end of the 10-d conditioning period. Tests will be run at 24-h (Day 11), 48-h (Day 12), and 96-h (Day 14). The chambers will be operated within a constant temperature incubator. The clean air supply will be derived compressed nitrogen, and flows will be set and monitored using mass-flow controllers (MFC). The outflow will have 2 ports for Tenax and 2 ports for DNPH cartridges.

PHI/DHS Tired-Derived Rubber Flooring Study
Extended Protocols for Material Emission Testing

Chamber C. Two 12 l stainless-steel chambers will be used for emission tests following the *Section 01350* protocol, i.e., longer term tests at 28-d, 60-d, and 90-d. The chambers will be operated in the laboratory space or incubator. All flows will be set and monitored using MFCs. The outflow will have 1 port each for Tenax and for DNPH cartridges. Quality control samples may be conducted using sequential samples.

CHEMICAL EMISSION TESTING

Emission testing protocols to be used in the current study will largely follow the DHS *Practice* and adhere to the *EHLB Standard Operating Procedure (SOP) Methods*^c (currently in draft form and being finalized):

- 114. *Small-scale Environmental Chamber for Materials Testing*
- 115. *Aldehyde Emissions from Building Materials*
- 116. *The Determination of Volatile Organic Compounds in Building Material Emission by Gas Chromatography / Mass Spectrometry*

For this study, flooring products will be tested in the 14-d test, and a several post-conditioning intervals. The testing of chemical emissions *after 14 days*, “long-term tests”, will follow these procedures:

- Specimens will be manually transferred from conditioning chambers to test chambers, then back to conditioning chambers.
- Testing will commence no less than 6 h after transfer.
- QC samples will be run in replicate, i.e., sequentially (e.g., Day 60 and Day 61), rather than as duplicate (i.e. in parallel).
- Sample volumes (flow x time) will be identical to Standard Tests (see Table 2).

Test Sequencing. Flooring specimens will go through a sequence of conditioning (in a specified environment) and testing at various times. The archetypical sequence follows the timeline shown in Table 3. The long-term tests will be conducted within 3% of the nominal test interval, i.e., 28-d test: ± 20 h; 60-d test: ± 43 d, and the 90-d test: ± 65 h

Screening Tests. Screening tests will be conducted on some component specimens, such as crumb rubber, buffing, flooring adhesives and sealers. The goal of screening is to semi-quantitatively identify the dominant chemicals emitted from these products^d.

- Rubber bits (crumb or buffing) will be placed into a packed column (10-20 cm long). Clean air (Chamber A air supply) will be pulled through the column, and air samples will be drawn through VOC and DNPH cartridges.
- Flooring adhesives and sealers will be tested using the wet product configuration, i.e., spread onto a stainless steel plate and placed into a conditioning vessel (Chamber A). After a ~24 h conditioning period, air samples will be drawn through VOC and DNPH cartridges.

^c DHS Environmental Health Laboratory Branch, 850 Marina Bay Parkway (G364/EHL), Richmond, CA 94804.

^d In the case of adhesives, their emissions are retarded when part of an assembly, relative to its solo application. Hence, these chemicals are expected to be released from the assembly for a longer time (albeit at lower rates).

PHI/DHS Tired-Derived Rubber Flooring Study
Extended Protocols for Material Emission Testing

Figure 1. Small Chambers

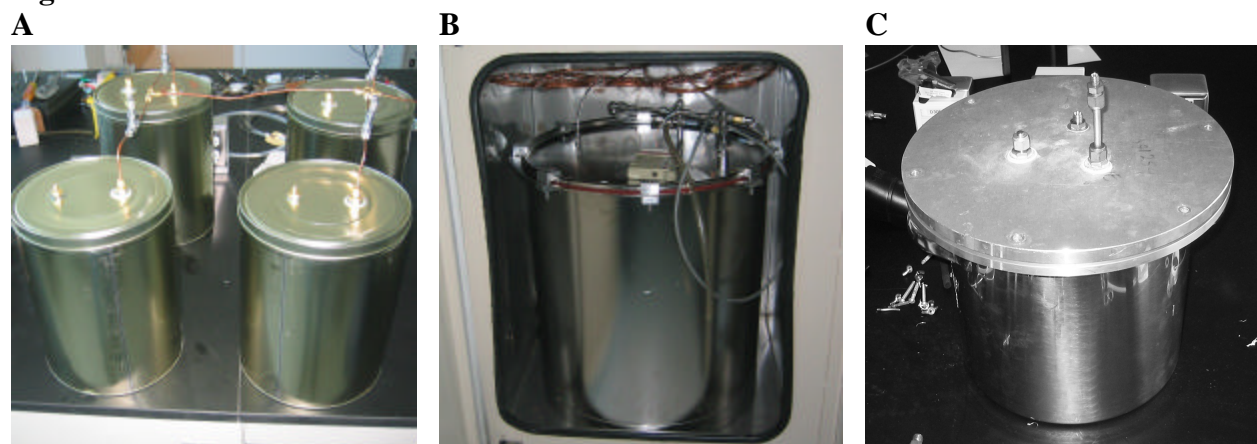


Table 1. Small Chamber Parameters

Chamber	Size	Location	Air supply	Sampling configuration	Air supply target
A “Conditioning”	16½ l	Lab bench	Lab air – C-trap & humidifier; Dry/Wet Rotometers	n/a	T=23±2°C, RH=50±10%, AER=1/h ±10%.
B “Section 01350” or Standard test	56 l	Incubator 1	LN ₂ & humidifier; Dry/Wet MFCs	2 Tenax ^(a) 1-2 DNPH ^(b)	T=23±1°C, RH=50±5%, AER=1/h ±5%.
C “Long-term” test	12 l	Incubator 2	Same as B	2 Tenax 1-2 DNPH	T/RH same as A AER same as B

^a Tenax or Dual-sorbent cartridge for individual VOC analyses

^b For aldehydes and ketones (e.g., formaldehyde)

Table 2. Chamber & Sample Cartridge Flows (REVISED – 8/9/2005)

Test / Chamber	Chamber Volume (Q)	Tenax flow*	DNPH flow*
Standard (B)	56 l (933 cc/min)	50 cc/min (3 h)	300 cc/min (2h)
Long-term (C)	12 l (200 cc/min)	50 cc/min (3 h)	100 cc/min (6h)

* Sample flows may not exceed 75% of total chamber Q

Table 3. Prototypical Testing Sequence of Chamber Use

Time								
0	1-10 d	10-14 d	15-27 d	28 d	29-59 d	60 d	61-89 d	90 d
Chamber: A	B	A	C	A	C	A	C	
10-d conditioning	Standard test	Extended Conditioning	28-d test	Extended Conditioning	60-d test	Extended Conditioning	90-d test	

PHI/DHS Tired-Derived Rubber Flooring Study
Extended Protocols for Material Emission Testing

Table 4. Timeline for Product Tests and Sample Collection

Calendar for Sample Testing

Key:		Conditioning	Std Test	28-day	60-day	90-day	Weekend/Holiday
Total Samples Tested:		6 Total includes duplicates					
Number of Samples		2		2	2		
Date	Day	No.	Set 1	Set 2	Set 3		
30-Sep	Fri	0	0				
01-Oct	Sat	1	1				
02-Oct	Sun	2	2				
03-Oct	Mon	3	3				
04-Oct	Tues	4	4				
05-Oct	Wed	5	5				
06-Oct	Thurs	6	6				
07-Oct	Fri	7	7	0			
08-Oct	Sat	8	8	1			
09-Oct	Sun	9	9	2			
10-Oct	Mon	10	10	3			
11-Oct	Tues	11	24-hr	4			
12-Oct	Wed	12	48-hr	5			
13-Oct	Thurs	13		6			
14-Oct	Fri	14	96-hr	7	0		
15-Oct	Sat	15		8	1		
16-Oct	Sun	16		9	2		
17-Oct	Mon	17		10	3		
18-Oct	Tues	18		24-hr	4		
19-Oct	Wed	19		48-hr	5		
20-Oct	Thurs	20			6		
21-Oct	Fri	21		96-hr	7		
22-Oct	Sat	22			8		
23-Oct	Sun	23			9		
24-Oct	Mon	24			10		
25-Oct	Tues	25			24-hr		
26-Oct	Wed	26			48-hr		
27-Oct	Thurs	27					
28-Oct	Fri	28	28-d		96-hr		
29-Oct	Sat	29					
30-Oct	Sun	30					
31-Oct	Mon	31					
01-Nov	Tues	32					
02-Nov	Wed	33					
03-Nov	Thurs	34					
04-Nov	Fri	35		28-d			
05-Nov	Sat	36					

2	2	2
Set 5	Set 6	Set 7
	</	

PHI/DHS Tired-Derived Rubber Flooring Study
Extended Protocols for Material Emission Testing

ATTACHMENTS

Attachment A. Survey for Manufacturer

Attachment B. Instructions to Manufacturers for Submission of Product Specimens

Attachment C. PHI Laboratory Chain-of-Custody Form

Public Health Institute / DHS
Tire-Derived Rubber Flooring Study

850 Marina Bay Parkway, G365/EHLB
 Richmond, California 94804

TIRE-DERIVED RUBBER FLOORING
INDUSTRY SURVEY

Paola Taranta ptaranta@phi.org
 Phone: 510 620-2856 Fax: 510 620-2825

Company Information:			
Name:		URL:	
Address:		Contact:	
City:		Title:	
State:		Phone:	
Postal Code:		Fax:	
Country:		Email:	

General Product Information:	
What are the names of the tire-derived interior-use rubber flooring that you sell?	
How many sq. ft. of tire-derived interior-use flooring do you sell per year?	

Manufacturing Information:	
What supplier(s) provides you with tires / tire-derived rubber?	
Are the tires from California?	
If not, what state / country do you / they get tires from?	
Do you use crumb rubber and / or tire buffings?	
Where are the rubber flooring manufacturing plant(s) located?	

Sales Information:	
What is the name of your biggest selling tire-derived indoor-use flooring?	
How many sq. ft. do you sell per year?	
Is your tire-derived interior- use flooring sold in California?	

Material Content Information:	
<i>Please answer the following questions about your best selling tire-derived flooring with indoor applications.</i>	
Do you use crumb rubber and / or tire buffings?	
What percent of the product is crumb rubber?	
What percent of the product is tire buffings?	
Do you add other types of rubber to the compound?	
If so, what types and percent of rubber do you add?	

Manufacturing Information:	
<i>Please answer the following questions about your best selling tire-derived flooring with indoor applications.</i>	
Do you manufacture, distribute and/or install this product?	
If you are not the manufacturer, which company manufactures the product?	
How often is the product manufactured?	
What is the next manufacturing date for this product?	
Is your product made with tire-derived rubber?	
Is your product used for interior and/or exterior applications?	
How would you describe the product? Is it poured-in-place, homogenous, layered product or some other type of product?	
What is the form of your product: a tile, mat, rolled, poured in place, paver or some other form?	
Is your product a flooring, a wall to wall product, and/or a mat, used in one area of a room?	
Is your product cured? If so, how is your product cured: compression, injection, or some other process?	
What is the maximum temperature of product production?	
Is a curative added? If so, what type of curative is used?	
Are accelerators used? If so, what types of accelerators are used?	
Is a binder used? If so, what type of binder is used?	
Is a fire retardant used? If so, what type of fire retardant is used?	
What is the density of the flooring product (lb/cubic ft or kg/cubic meter)?	

Installation and Maintenance:	
<i>Please answer the following questions about your best selling tire-derived flooring with indoor applications.</i>	
Do you recommend the use of an adhesive?	
If so, which adhesive do you recommend?	
Do you recommend the use of a sealant?	
If so, which sealant do you recommend?	

California Integrated Waste Management Board (CIWMB) Grants:	
Have you received a CIWMB grant?	
If so, what year did you receive a CIWMB grant?	

INSTRUCTION TO MANUFACTURERS FOR SUBMISSION OF PRODUCT SPECIMENS

Introduction

These instructions summarize the protocols to be used in the submission -- collection, handling, packaging, and documentation -- of product specimens for emissions testing to the Public Health Institute (PHI) study. The aim is to provide for testing specimens that are representative of the product manufactured under typical production conditions. The specimens for testing need to be protected from chemical contamination and exposure to high temperatures (>25° C). Personnel in charge of submitting specimens should read these instructions through before starting, and then perform the tasks conscientiously and faithfully. Adhering to these instructions will ensure that specimens tested are reliable, representative, uncontaminated, and well preserved, and that the emissions testing results satisfy *Section 01350*. If tasks are done improperly, the results may be in error, and the testing will be invalid. These protocols are based on the California Department of Health Services (DHS) *Standard Practice*, and are consistent with European Committee for Standardization (2002).

Collection/Shipping/Testing Schedule

It is essential that production completion dates for all specimens submitted be accurately determined and recorded.

All specimens, with the exception of containerized products, must be collected at the manufacturing facility and delivered to the laboratory **within 7 days** of the production completion date. Containerized products (i.e., paints, sealants, adhesives, and other wet products) must be collected and delivered **within 3 months** of production. Ideally, specimens should be shipped within 24 hours of actual collection (see Table 1).

Specimen Storage and Shipment

Specimen storage containers and labels are available to the manufacturer from the PHI laboratory. The manufacturer may supply its own storage containers, provided these meet the laboratory specifications¹. Specimens should be stored immediately after collection in the storage container (airtight, moisture-proof packaging) to prevent contamination or subsequent VOC emission losses. Only one product shall be placed in an individual storage container.

Shipment of specimens should be done using standard packaging, such as a cardboard box or other container, suitable to protect the storage container from being damaged or punctured during shipment. Multiple specimens in separate containers may be shipped together. Product specimens should be shipped from the collection site within 24 hours of collection. Multi-day

¹ Heavy-duty aluminum foil; air-tight polyethylene or Mylar bag.

delivery is acceptable, provided delivery to the laboratory is achieved per the required schedule (see Table 1).

Table 1. Product Type and Schedule
<p><i>Dry Products (e.g., resilient flooring, carpet, wallcovering, etc.)</i></p> <p>Delivery to laboratory: No more than 7 days after production completion</p> <p>Commence laboratory testing²: Within 4±1 (3-5) weeks of production</p> <p><i>Containerized products (e.g., adhesive, sealant, paint, etc.)</i></p> <p>Delivery to laboratory: No more than 3 months after production completion</p> <p>Commence laboratory testing: No more than 3 months, 2 weeks after production</p>

Specimen Collection Procedures

Handling for collection and packaging should be completed within 1 hour. Separate procedures are used for different product categories³.

Sheet and roll goods greater than 3-feet wide. These include sheet or roll flooring or cushion, broadloom carpet, and wall-covering fabrics.

- Specimens collected within 24-h of production can be taken directly from the end of the product roll. Specimens collected more than 24-h from production should be taken a minimum of two full roll circumferences from the end of the roll.
- Cut a strip approximately one-foot wide across the width of the roll. Discard at least one foot from each end of the strip.
- Cut the remaining material into approximate 12 x 12-inch squares. A minimum of four squares is required.
- Stack the squares tightly together front-to-back.
- Wrap tightly with two layers of heavy-duty aluminum foil. Minimize the air space and crimp the seams to create an airtight seal. To assure air tight seams (if necessary), seal the seams of the outer layer of aluminum foil with clear packaging tape (e.g., 3M Scotch Brand, 3850 series).
- Attach an identification label (or a copy of the chain-of-custody form) to the foil package.
- Place the foil package in a clear polyethylene or Mylar bag; attach another identification label (or a copy of the chain-of-custody form) to the outside of the bag.
- Specimens of sheet and roll goods sent to a laboratory shall be accompanied by a Material Safety Data Sheet (MSDS) and a specification sheet that describe the products, list the major chemical ingredients, identify the intended uses and describe the installation and application methods.

² Laboratory testing may commence prior to 3 weeks of production to meet a specific deadline. Early commencement must be requested by the manufacturer

³ If the preparation of a product specimen by the testing laboratory requires specialized equipment, the laboratory may request a fully prepared test specimen to be fabricated by the manufacturer.

Tile, strip, panel and plank products less than or equal to 2-feet wide. These include flooring tiles, such as rubber, carpet, linoleum, vinyl, flooring strips, and ceiling tiles.

- Product specimens should be collected directly from the packing line, when possible. If specimens are obtained from consumer packages, interior (not end) pieces should be selected
- Collect a minimum of four representative tiles, strips or planks, each with a minimum surface area of at least 64 square inches (8"x8"). For example, a single 18 x 18-inch or 24 x 24-inch tile or panel may be cut into four equal squares.
- Stack pieces front-to-back.
- Wrap tightly with two layers of heavy-duty aluminum foil. Minimize the air space and crimp the seams to create an airtight seal. To assure air tight seams (if necessary), seal the seams of the outer layer of aluminum foil with clear packaging tape (e.g., 3M Scotch Brand, 3850 series).
- Attach an identification label (or a copy of the chain-of-custody form) to the foil package.
- Place the foil package in a clear polyethylene or Mylar bag; attach another identification label (or a copy of the chain-of-custody form) to the outside of the bag.
- Specimens of tile, strip, panel and plank products sent to a laboratory shall be accompanied by a Material Safety Data Sheet (MSDS) and a specification sheet that describe the products, list the major chemical ingredients, identify the intended uses and describe the installation and application methods.

Containerized products. These include adhesives, sealants, paints, other coatings, primers and other “wet” products.

- Paints, other coatings and primers may be supplied in the original consumer packaging, e.g., 1-quart or 1-gallon container.
- Adhesives can be supplied in the original consumer packaging, e.g., an applicator tube or container.
- Alternately, specimens of adhesives can be collected in clean, unused paint cans (e.g., 1-pint or 1-quart size). Special care is required to assure these specimens are representative of the larger batches from which they are collected. Containers should be filled so there is minimal unfilled headspace. The collection procedure shall be documented.
- Attach an identification label (or a copy of the chain-of-custody form) to the container.
- Specimens of containerized products sent to a laboratory shall be accompanied by a Material Safety Data Sheet (MSDS) and a specification sheet that describe the products, list the major chemical ingredients, identify the intended uses and describe the installation and application methods.
- If specialized tools are required to apply a containerized product to a substrate (e.g., a specific notched trowel not readily obtainable in a hardware store) these tools also shall be supplied to the laboratory.
- The laboratory reserves the right to return the unused portion of any containerized product to the organization supplying the product for testing.

Chain-of-Custody Documentation

An individual PHI laboratory chain-of-custody form⁴ must accompany **each** product specimen. Every person involved in the collection, handling, and shipping is required to sign, date and transmit the original form (see Appendix).

⁴ Available at: www.ca-liaq.org/TIRE

Rejection of Specimens by Laboratory

If specimen handling, shipment, or documentation is not carried out correctly, the PHI laboratory may reject a received specimen. The following are among the reasons specimens would be rejected:

- Shipping package or specimen storage container is severely damaged upon arrival.
- Chain-of-Custody form is missing or incomplete.
- Specimen arrives after required time frame (Table 1).

When a product specimen is rejected, the testing laboratory will inform the manufacturer within two days of the decision and provide the reason for rejection. The manufacturer may collect a new specimen and resubmit it for testing, subject to the conditions described within this protocol.

Updated: 2005-09-07

Public Health Institute / DHS

Tire-Derived Rubber Flooring Study
 850 Marina Bay Parkway, G365/EHLB
 Richmond, California 94804

CHAIN OF CUSTODY

Paola Taranta ptaranta@phi.org
 Phone: 510 620-2856 Fax: 510 620-2825

Company Information:			
Name:		URL:	
Address:		Contact:	
City:		Title:	
State:		Phone:	
Postal Code:		Fax:	
Country:		Email:	

Specimen Details:	
Product Name / ID:	
Product Category / Subcategory:	
Plant Location:	
Sample Collected by:	
Date & Time Collected:	
Number of Sample Pieces:	
Date Manufactured:	

Shipping Details:	
Packed By:	
Shipping Date:	
Carrier:	
Airbill Number:	

Notes or Comments from Manufacturer:	Sample ID / Bar Code Label

Change of Custody / Specimen Handling:		
Date	Delivered by: Name and Company	Received by: Name and Company

Laboratory Receipt:	
To Be Filled Out By Laboratory Staff Only	
Received By:	
Received Date:	
Condition of Shipping Package:	
Condition of Specimen:	
Sample ID:	
Notes or Comments:	

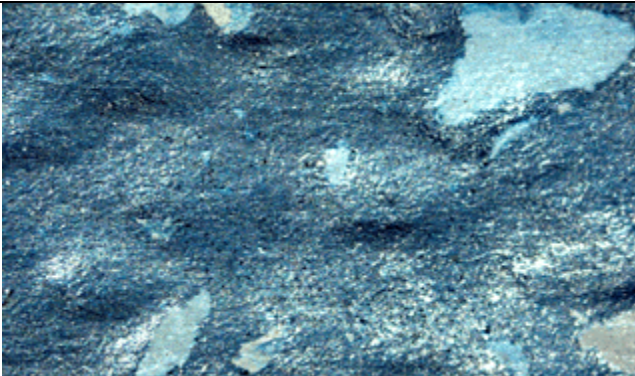
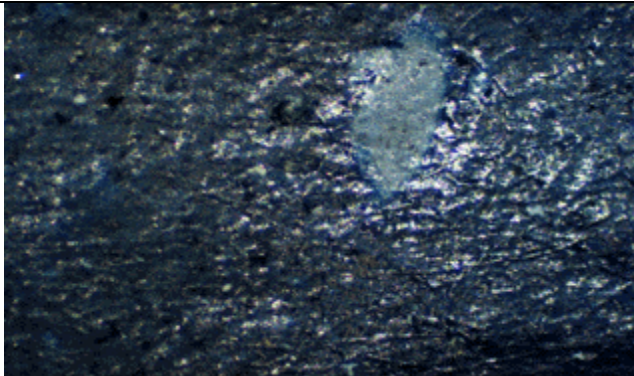
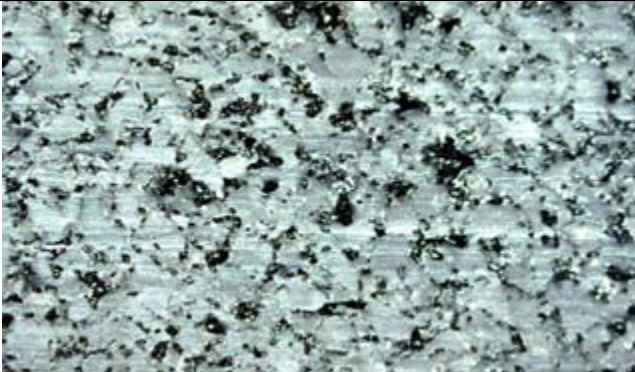
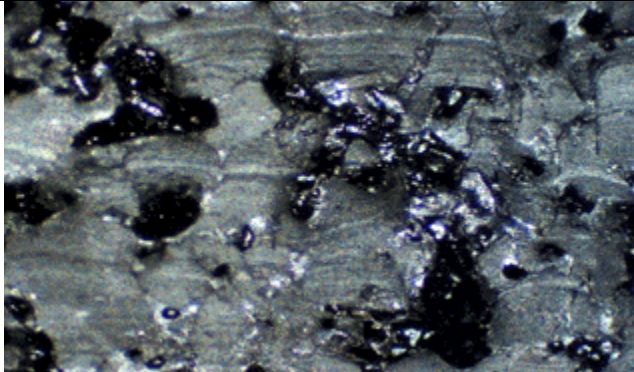
TDR Sampling Data Sheet

<u>Sample Information</u>	
Lab ID _____	
Conditioning. Date_____	Sampling Date_____
Sampling Type (circle): 11-d 12-d 14-d 28-d 60-d 90-d	
Chamber / LT(circle): 1 2	
Analyst: _____	
<u>VOCs Sampling</u>	
Tube #_____	Sampling Rate_____
Starting Time_____	Ending Time _____
Analyst ID: _____	Analyst ID: _____
<u>Aldehydes Sampling</u>	
Starting Time_____	Ending Time _____
Analyst ID: _____	Analyst ID: _____
Sampling Rate_____	
Sample Final Weight_____	
Notes:	

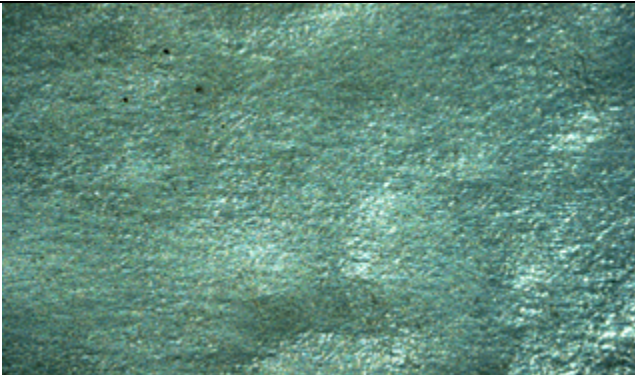
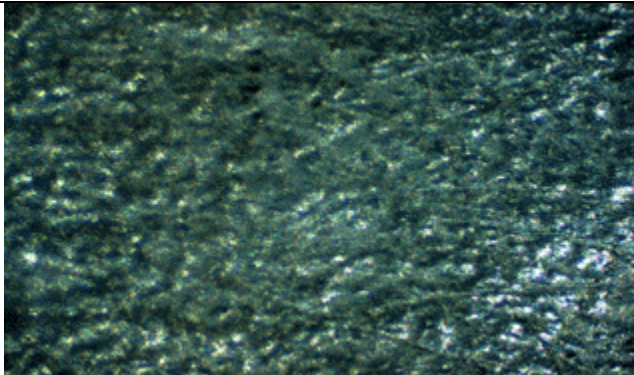
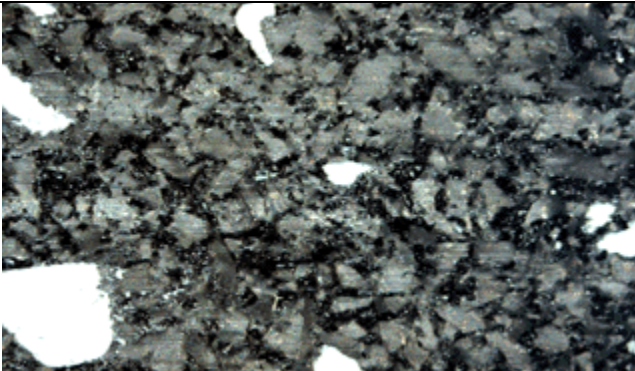
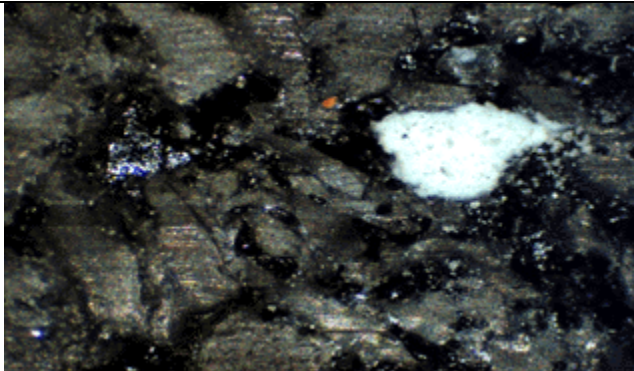
Appendix C. Microscopic Images of Products Tested in Study

This page intentionally left blank.

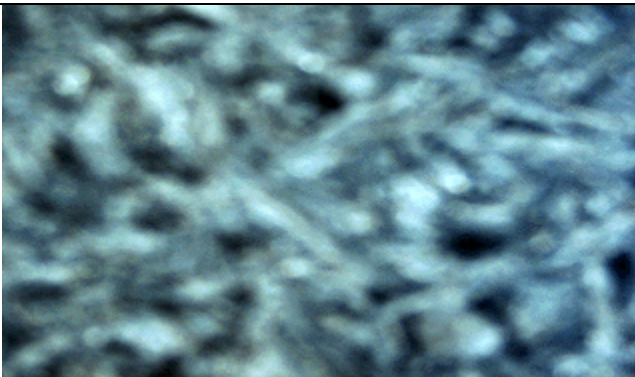


Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 1.1.1 (Lab No. 002)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

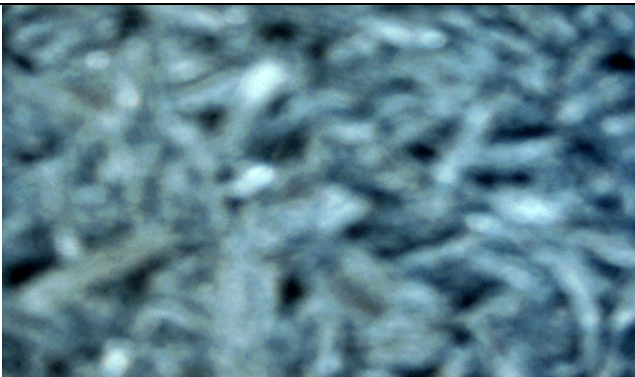

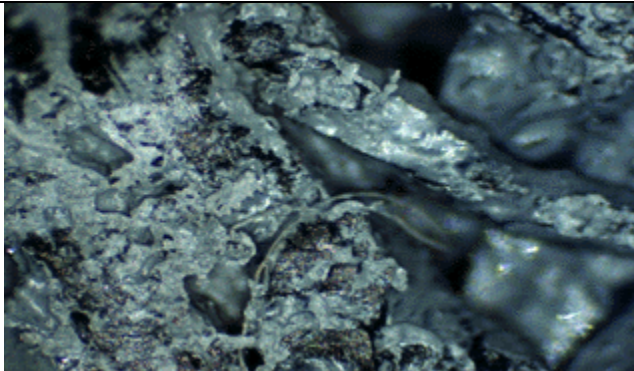
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 1.2.1 (Lab No. 061)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

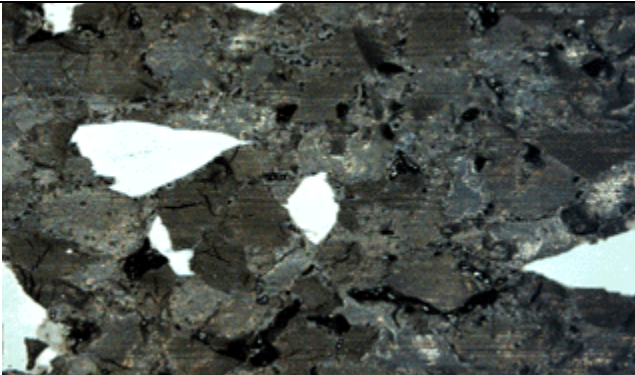
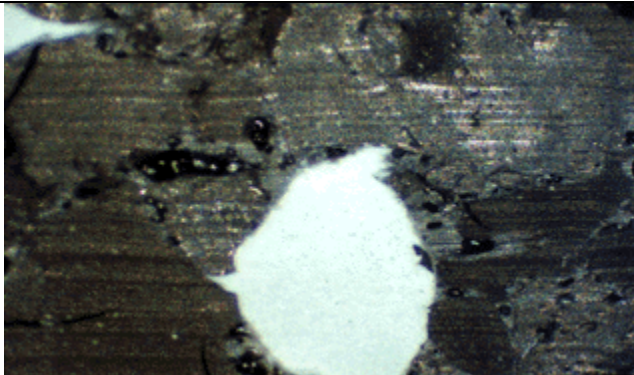
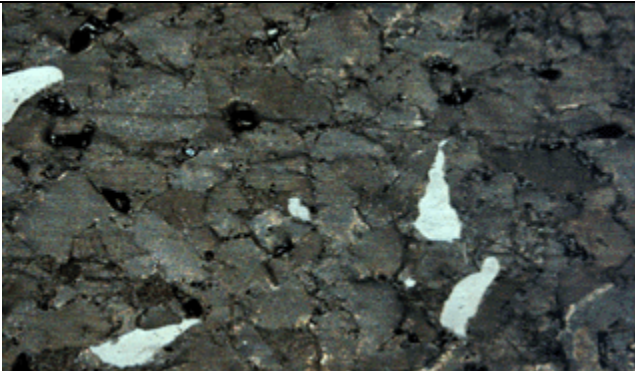
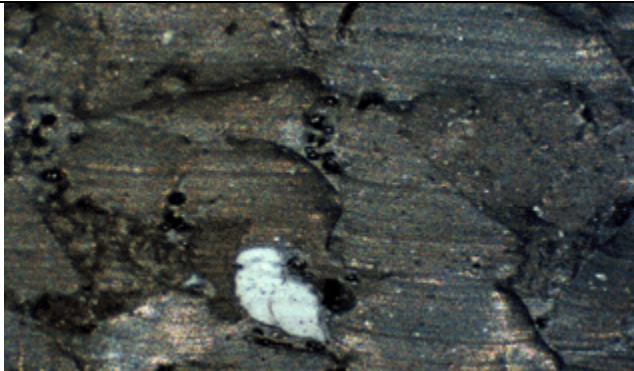
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 2.1.1 (Lab No. 022)			
	Magnification 6.3x		Magnification 40x	
Top View				NA
Bottom View				

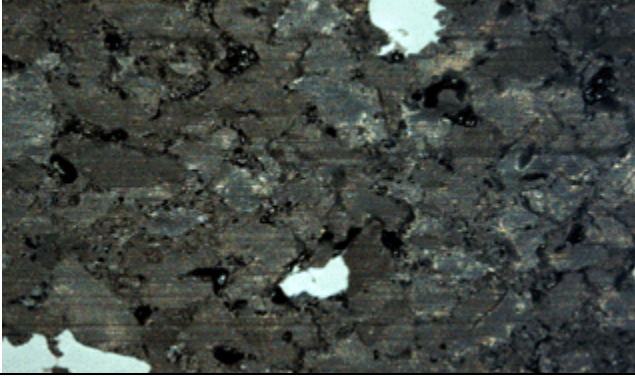
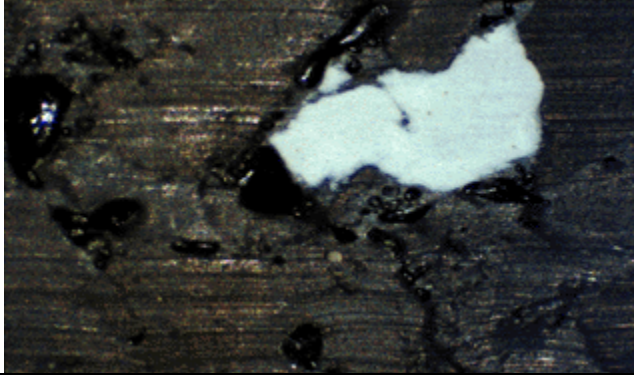
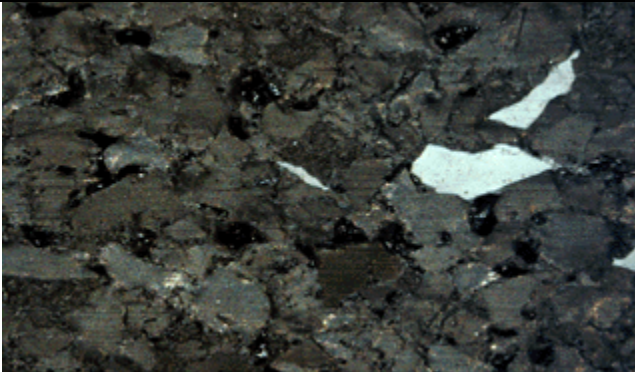
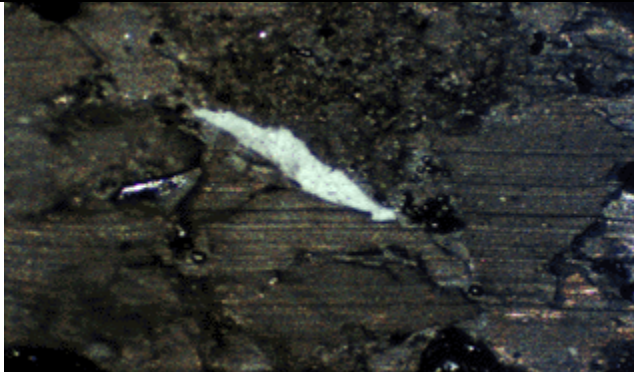
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 2.1.2 (Lab No. 023)		
	Magnification 6.3x		Magnification 40x
Top View			NA
Bottom View			

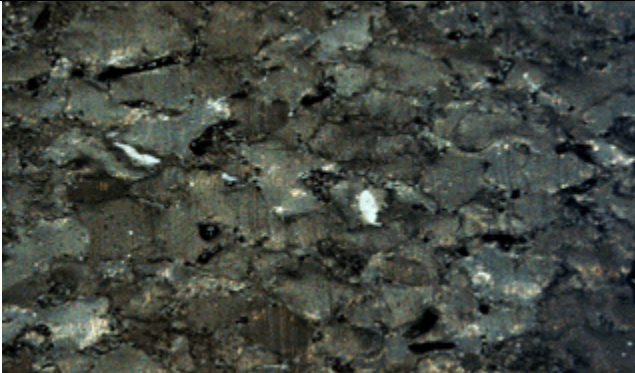
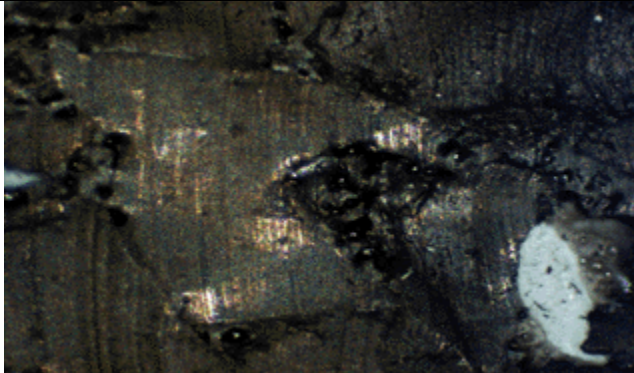
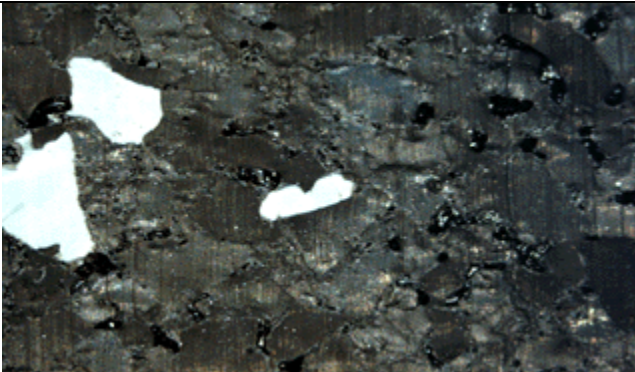
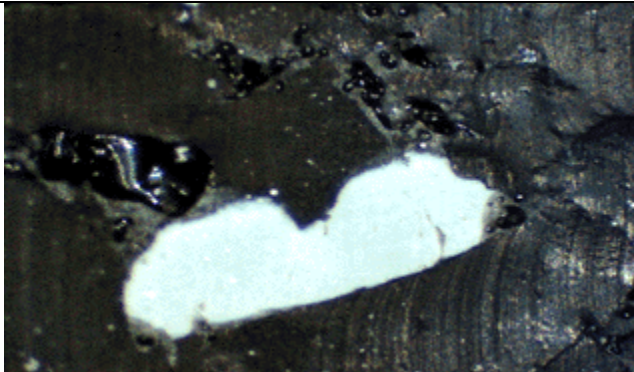
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.1.1 (Lab No. 007)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

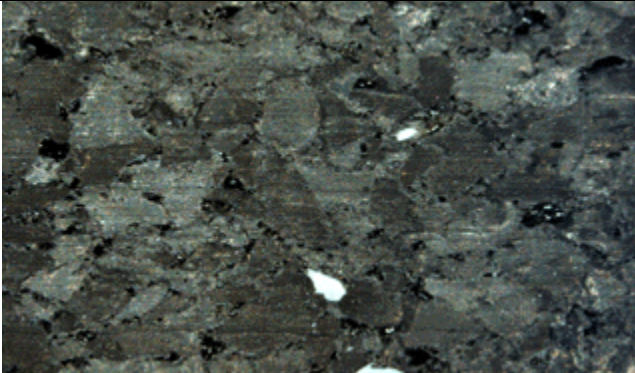

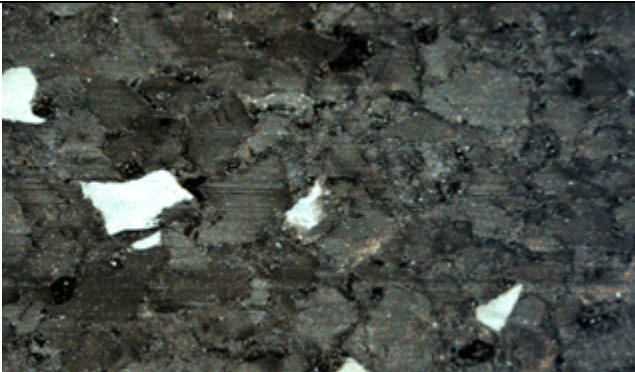

Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.1.2 (Lab No. 008)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

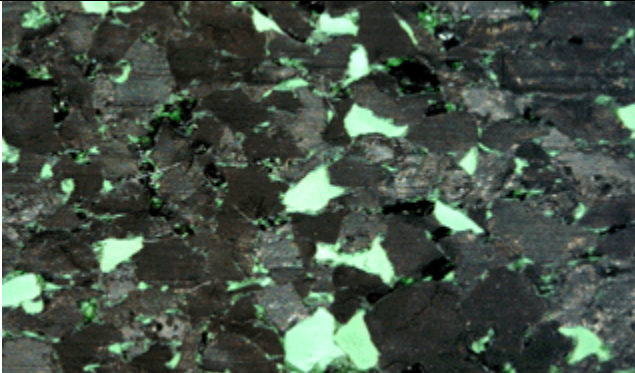
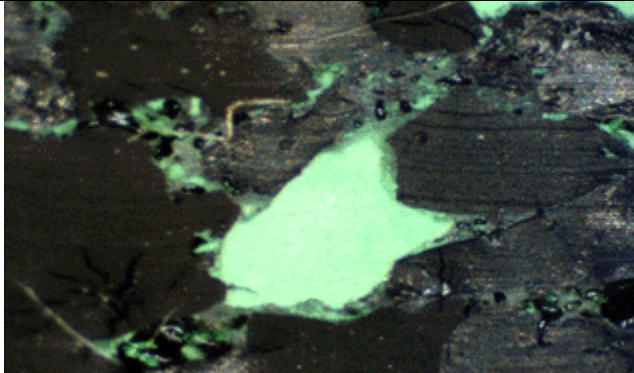
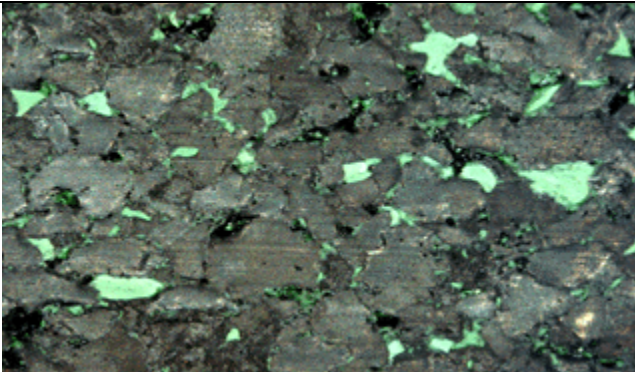
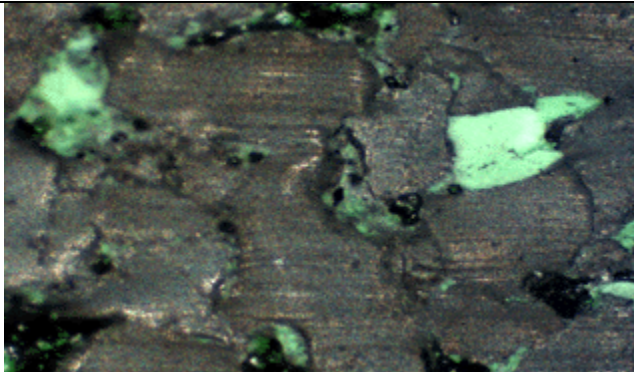
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.1.3 (Lab No. 076)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

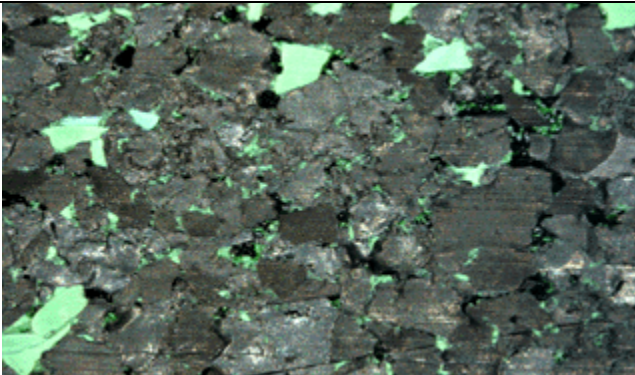
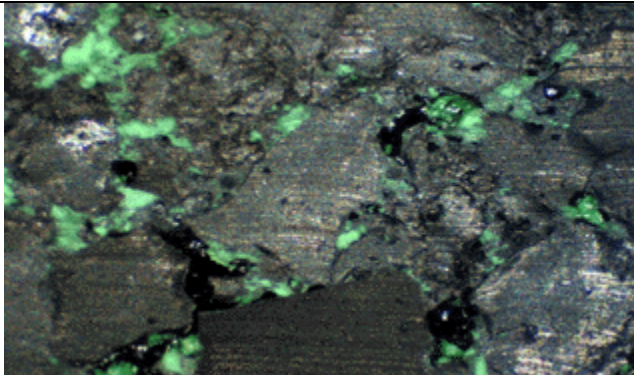
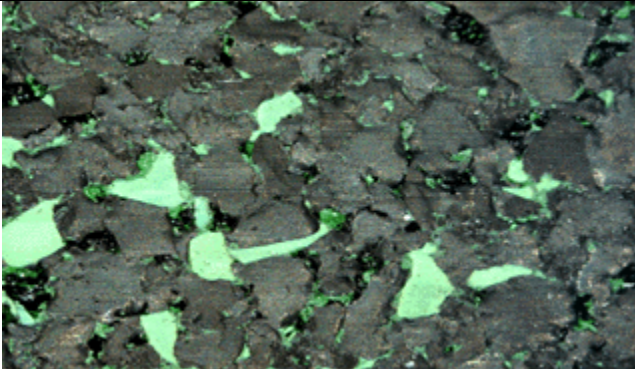
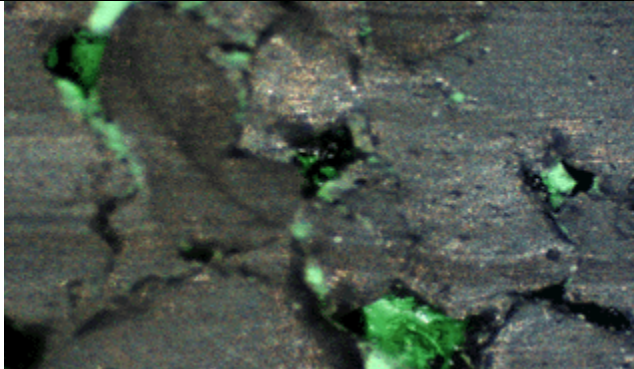
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.1.3 (Lab No. 077)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

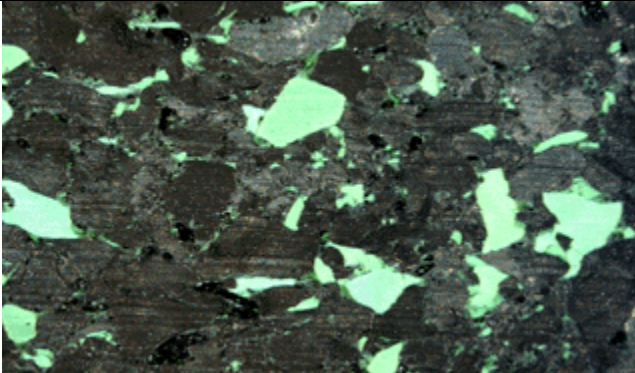
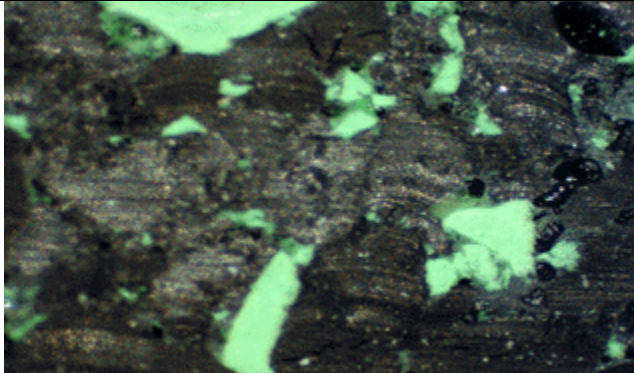
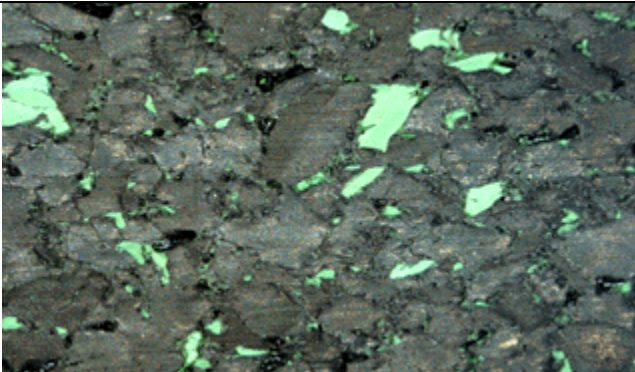
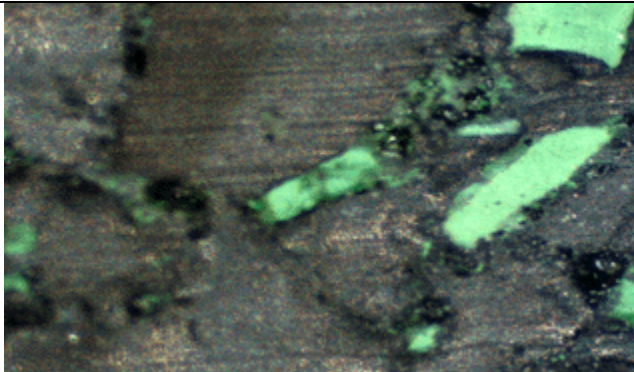
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.2.1 (Lab No. 009)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				


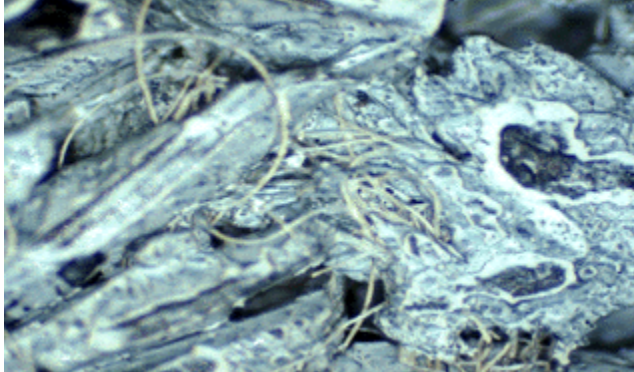
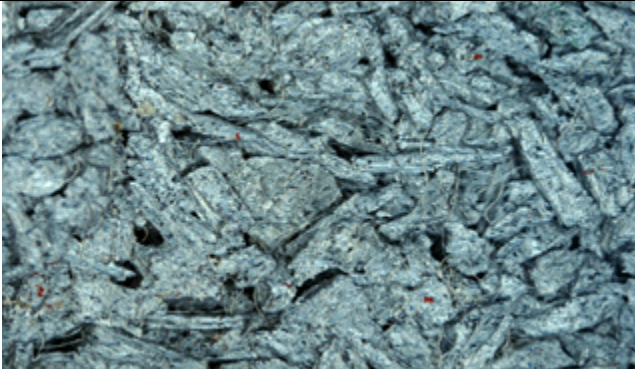
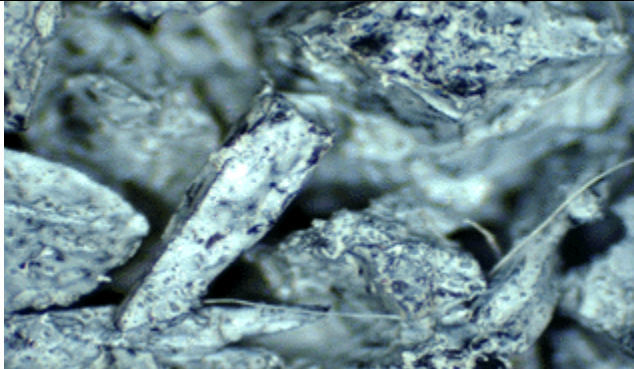
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.2.2 (Lab No. 010)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

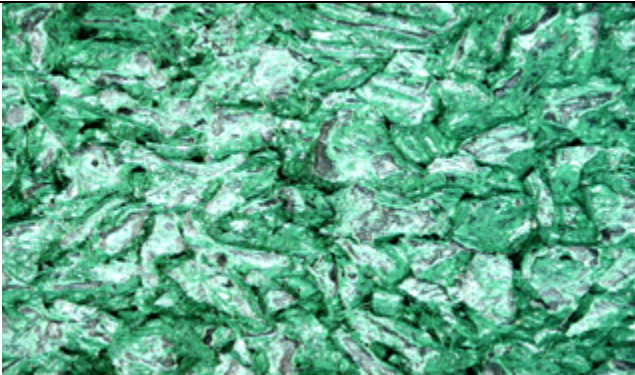
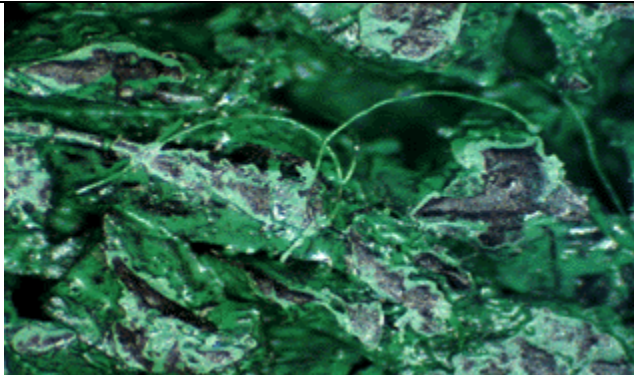

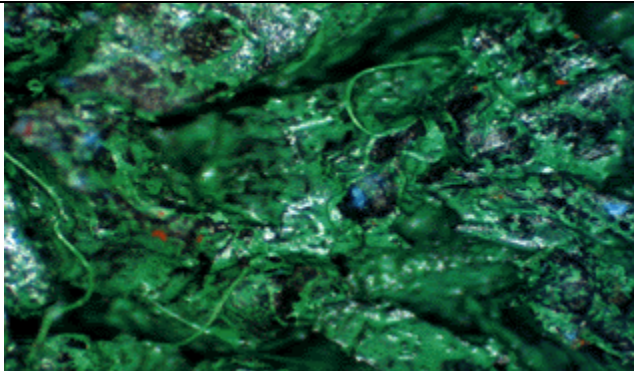
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 3.2.3 (Lab No. 078)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				


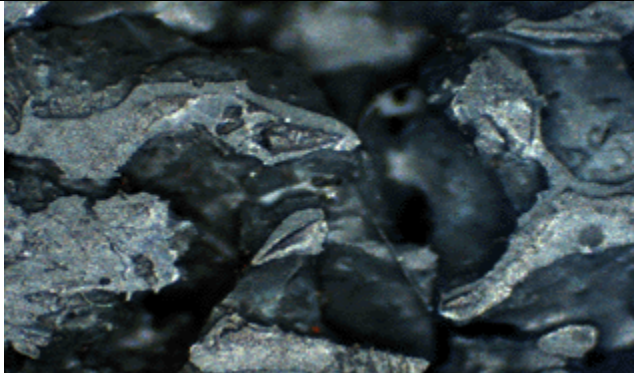
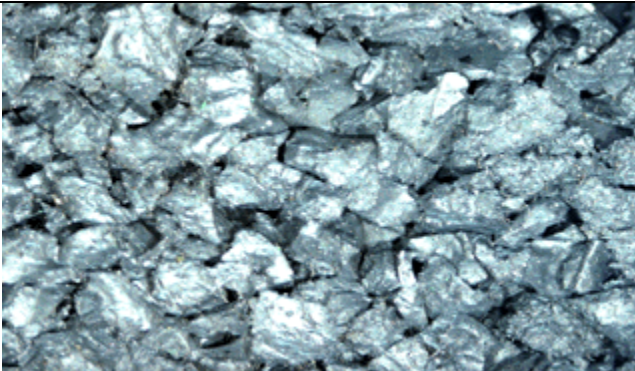
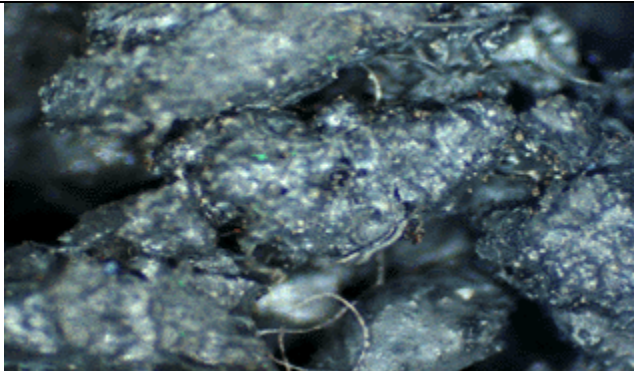
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 4.1.1 (Lab No. 032)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				


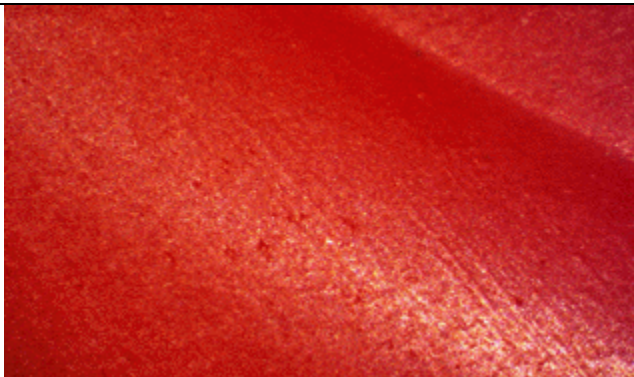
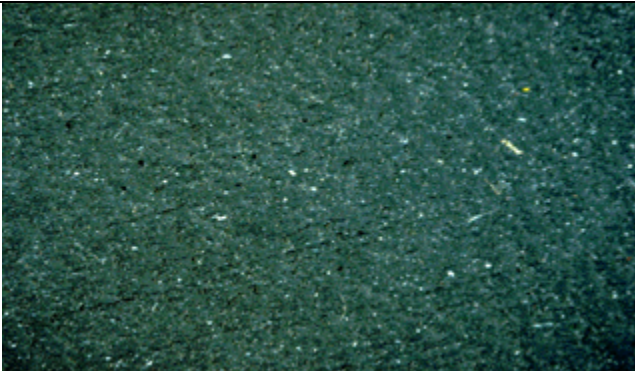
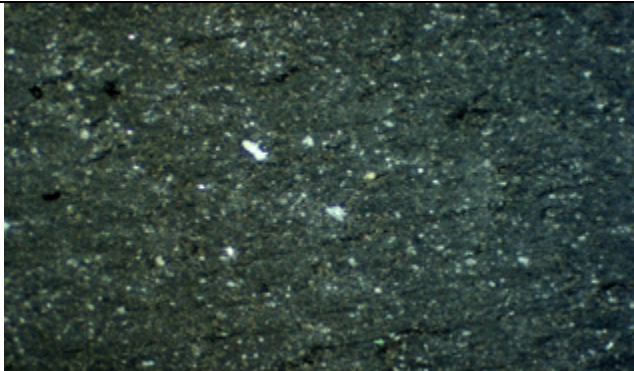
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 4.2.1 (Lab No. 031)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

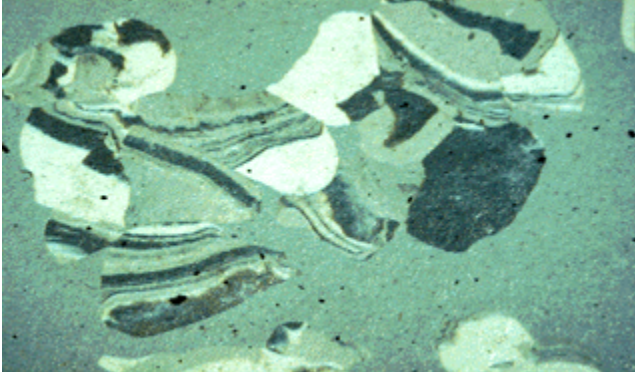
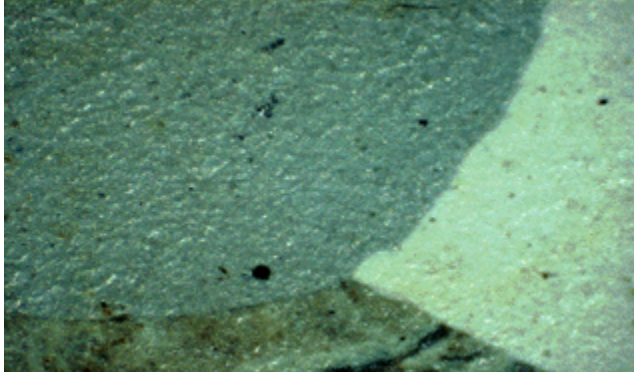
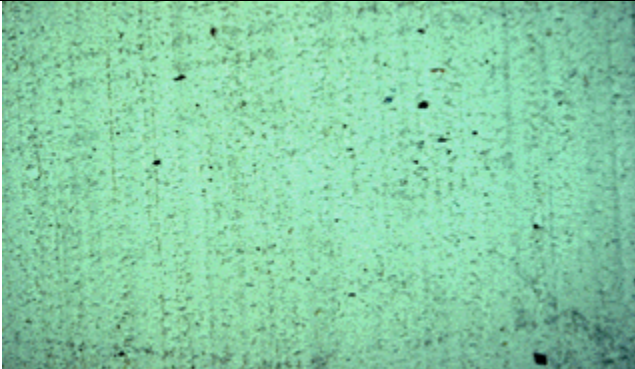
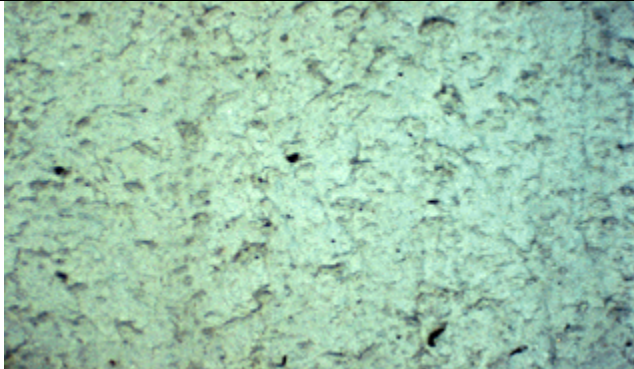
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 4.3.1 (Lab No. 071)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

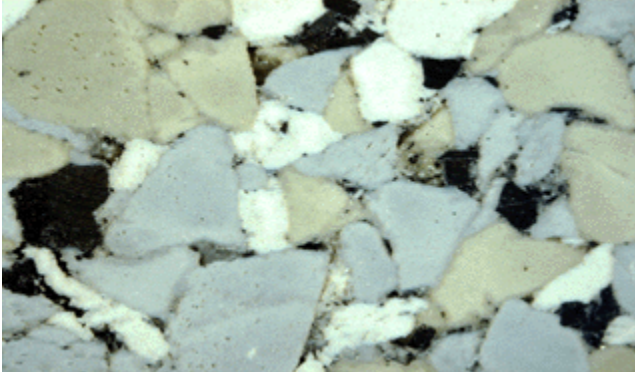
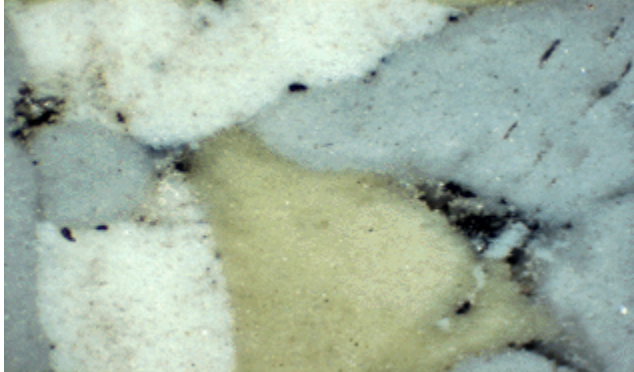
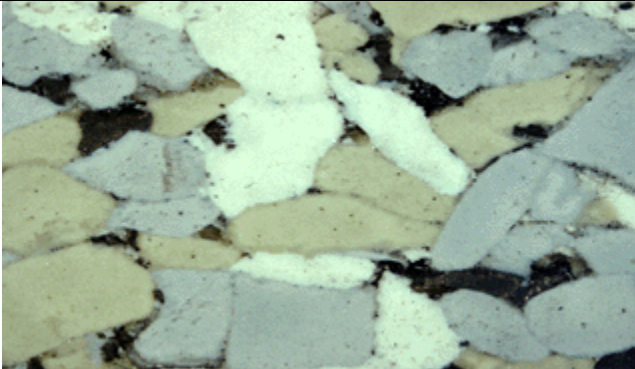

Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 5.1.1 (Lab No. 052)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				


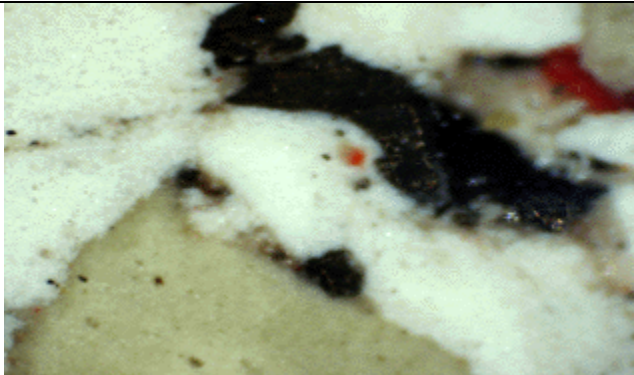

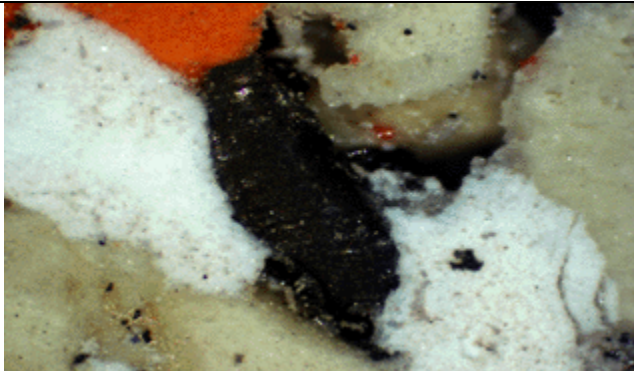
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 5.2.1 (Lab No. 051)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

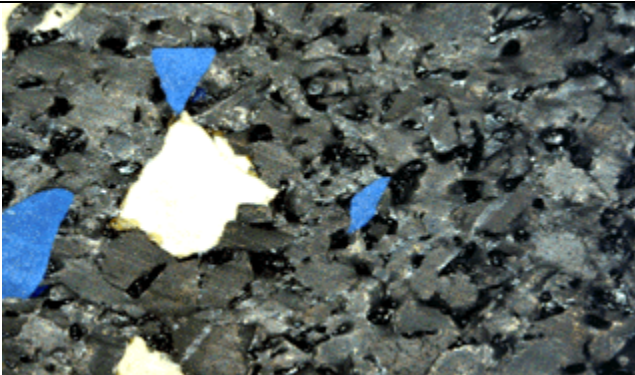
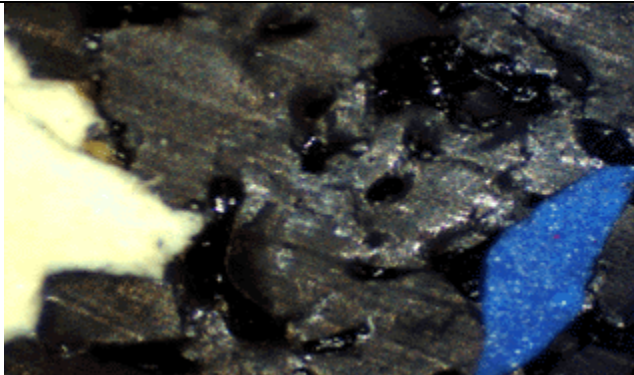
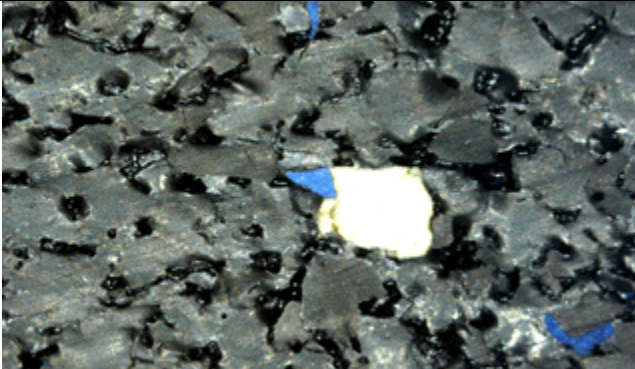
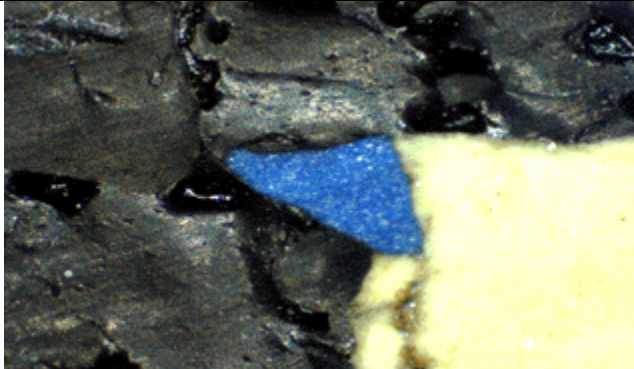
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 6.1.1 (Lab No. 082)	
	Magnification 10x	Magnification 40x
Top View		
Bottom View		

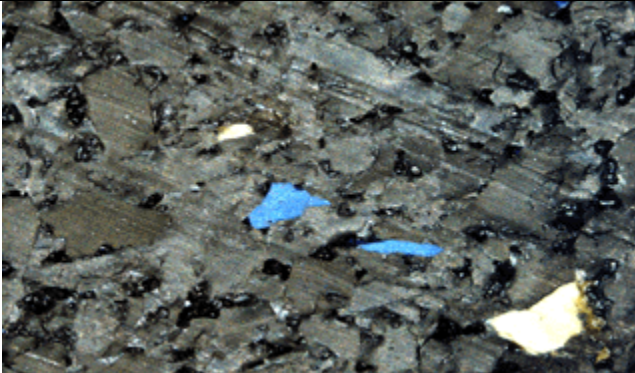
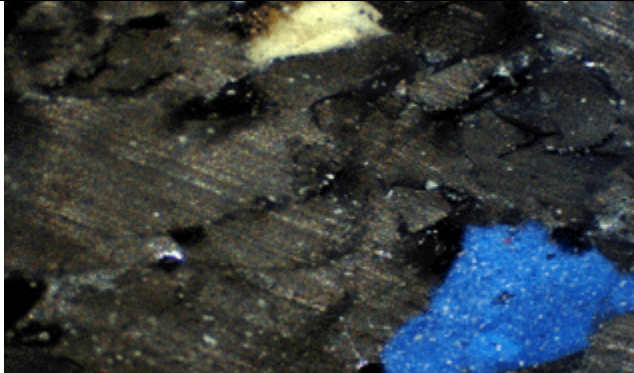
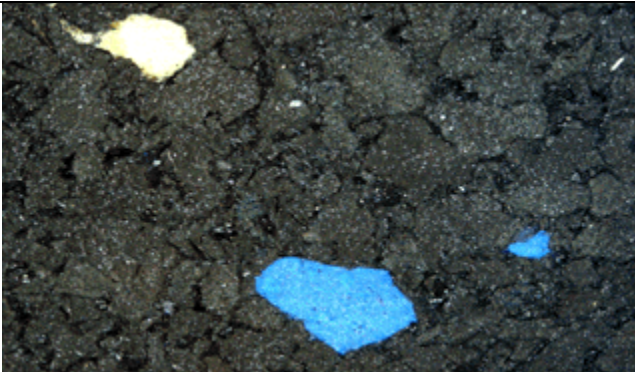
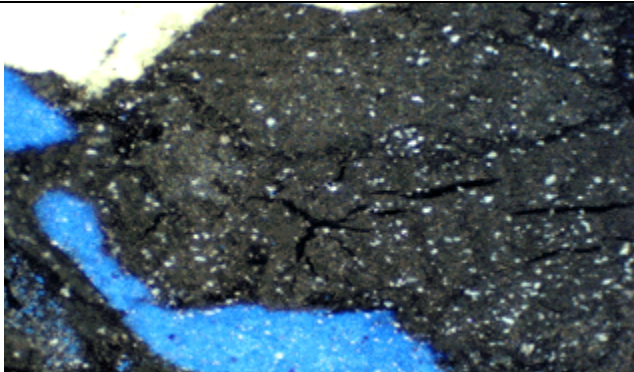
Tire-Derived Rubber Flooring Chemical Emissions Study

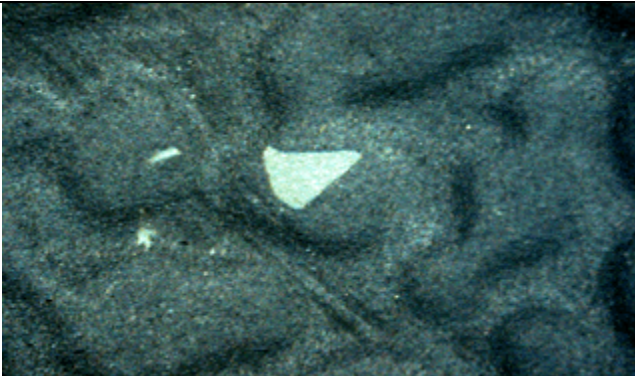

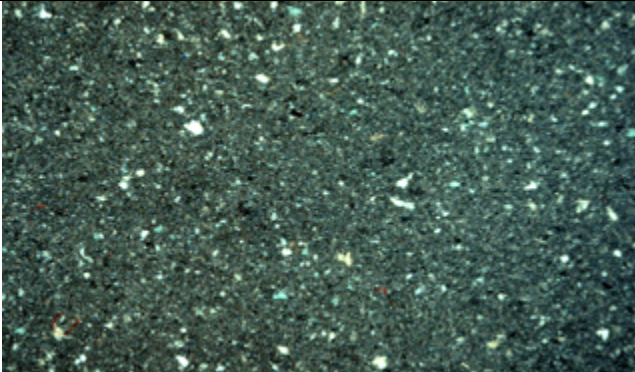
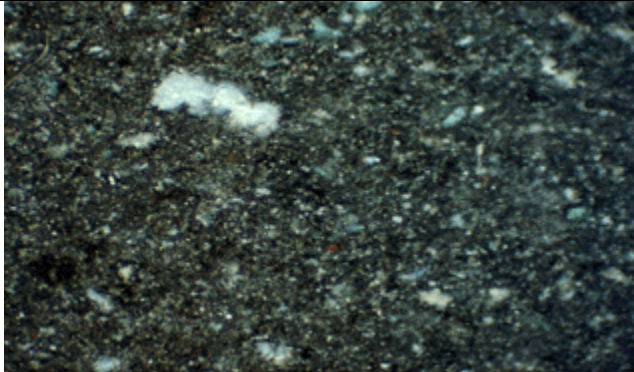
	Product No. 6.2.1 (Lab No. 102)	
	Magnification 10x	Magnification 40x
Top View		
Bottom View		

Tire-Derived Rubber Flooring Chemical Emissions Study

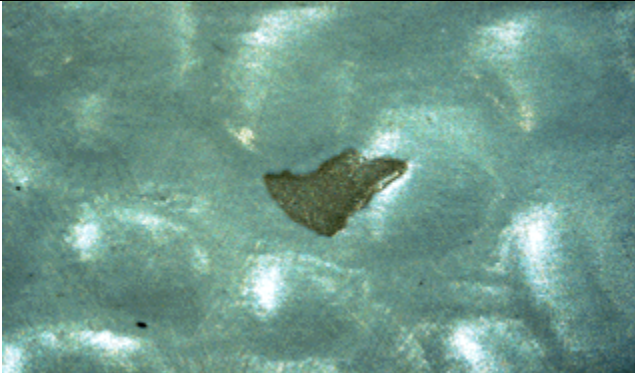
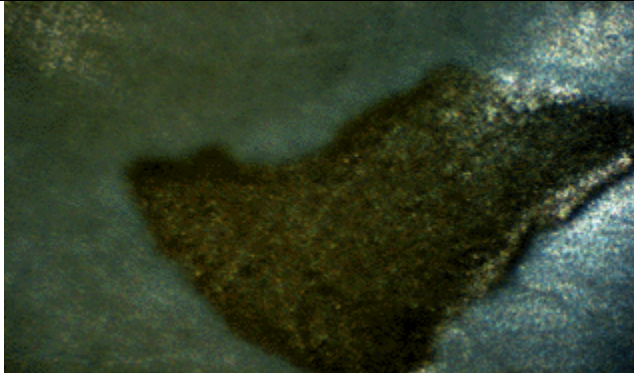
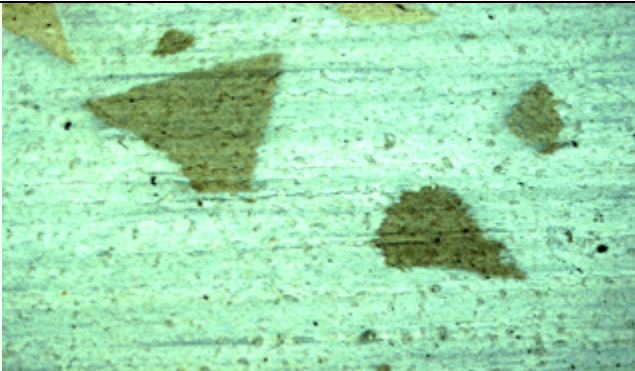
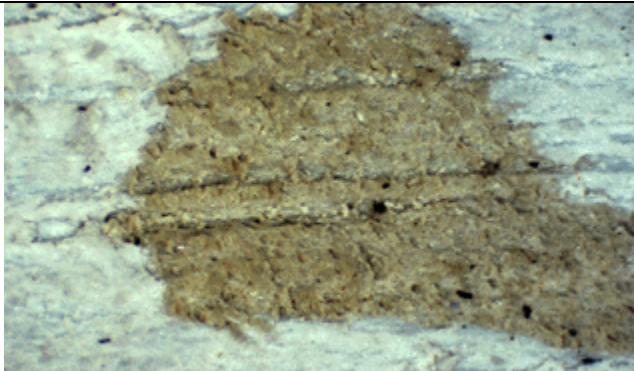
	Product No. 6.3.1 (Lab No. 081)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

Tire-Derived Rubber Flooring Chemical Emissions Study

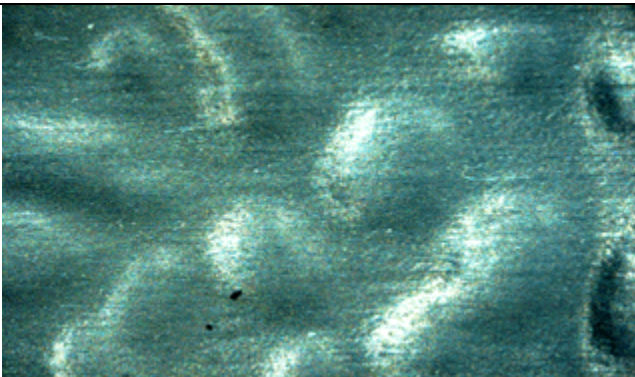

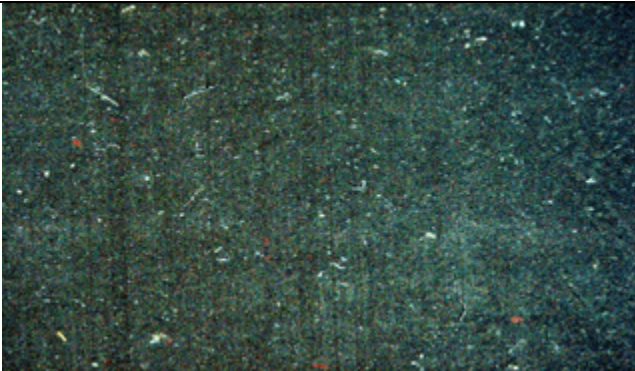
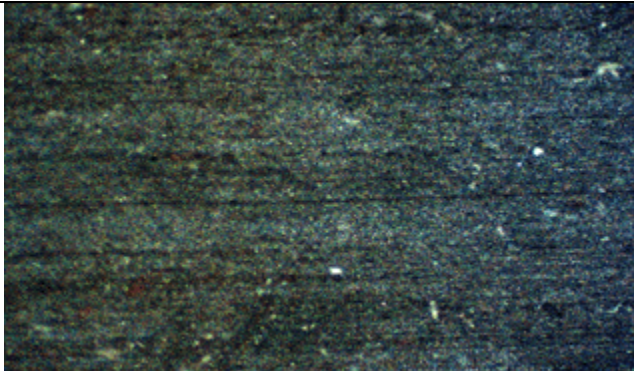
	Product No. 6.3.2 (Lab No. 100)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

	Product No. 6.4.1 (Lab No. 083)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

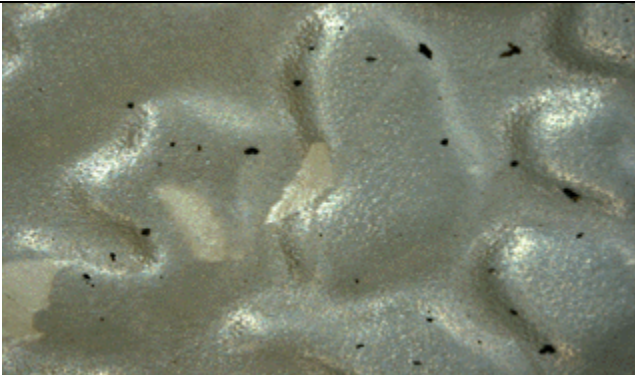
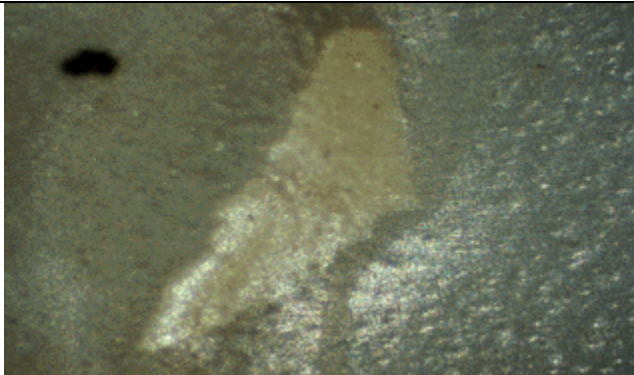
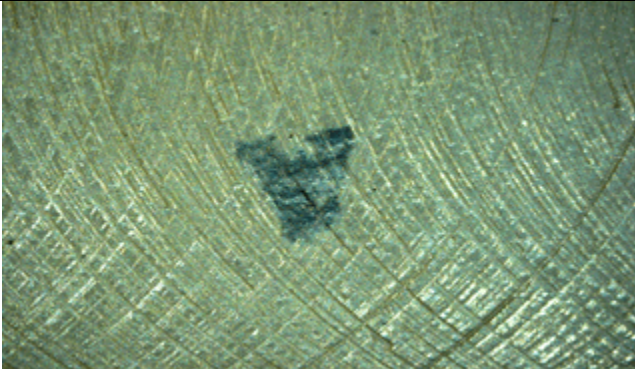

Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 6.5.1 (Lab No. 085)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

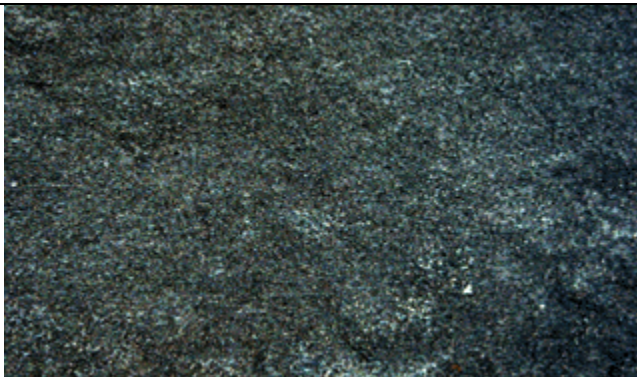
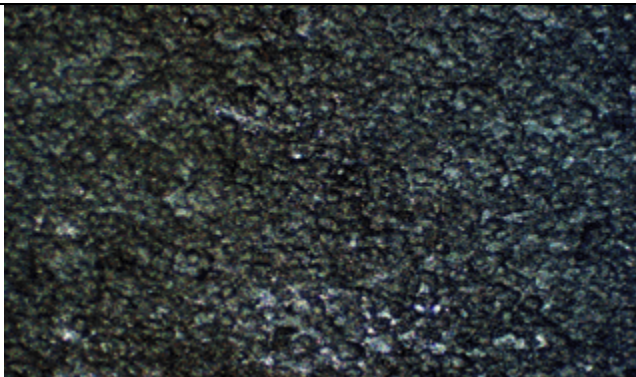

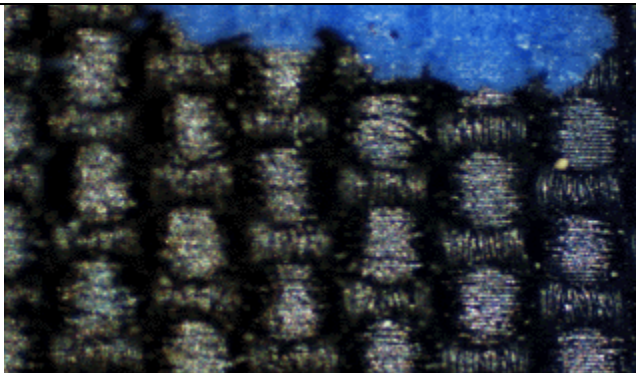
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 6.6.1 (Lab No. 103)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

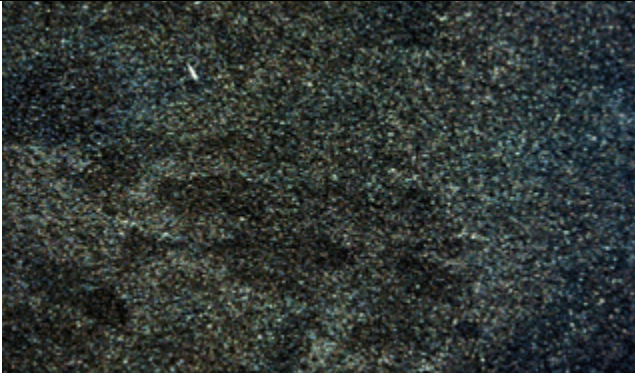
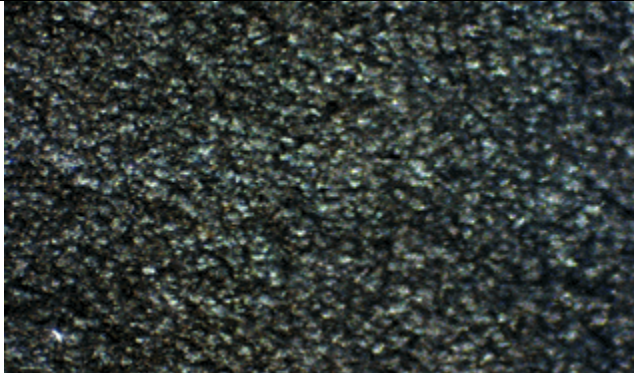
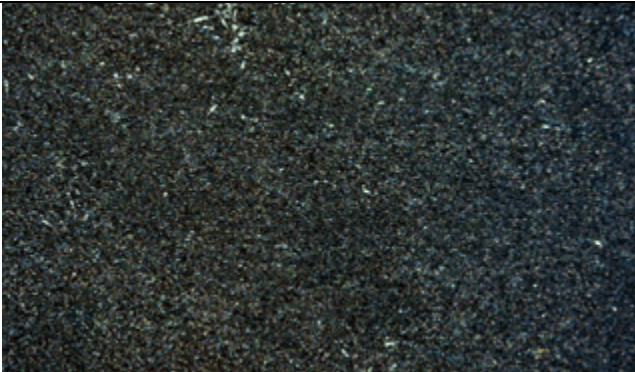
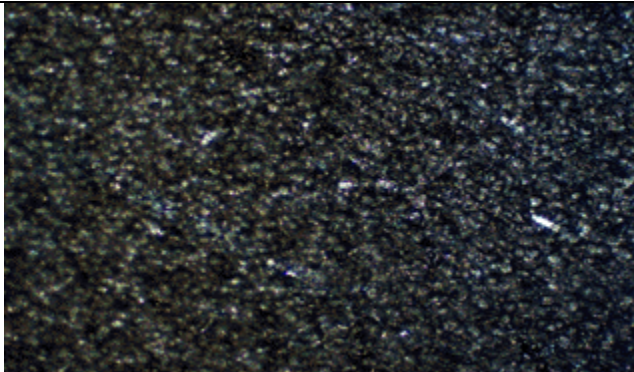
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 6.7.1 (Lab No. 104)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

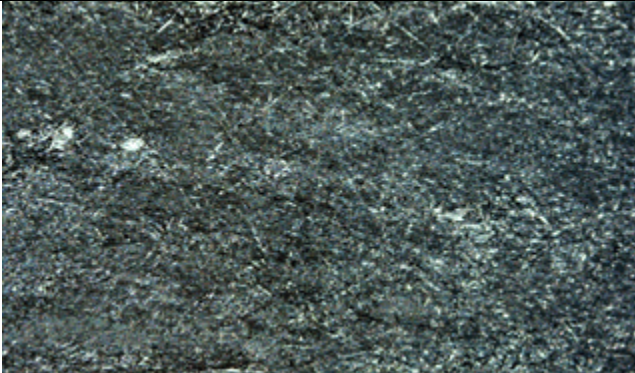
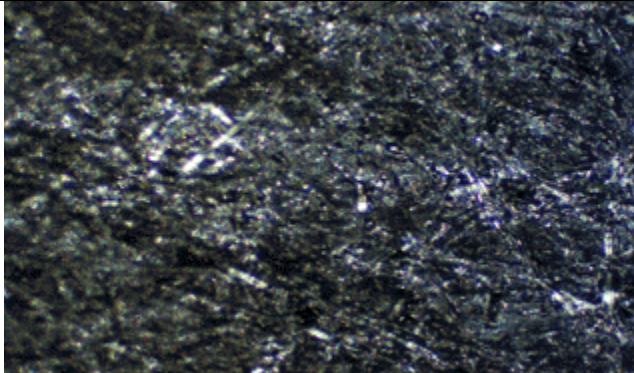
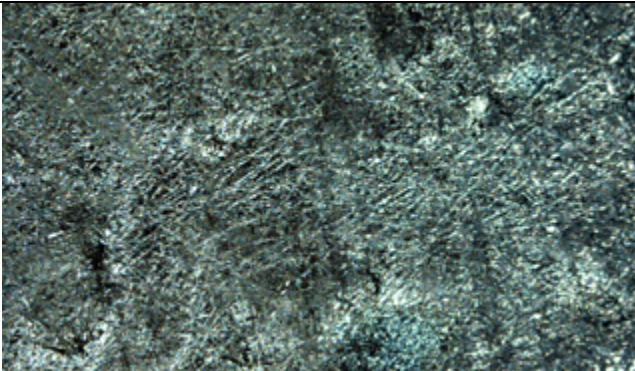
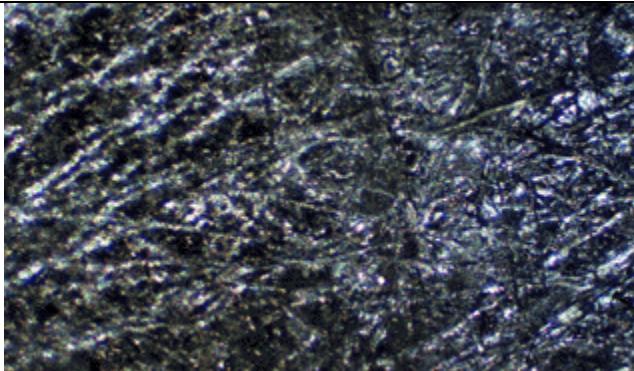
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 7.1.1 (Lab No. 047)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				


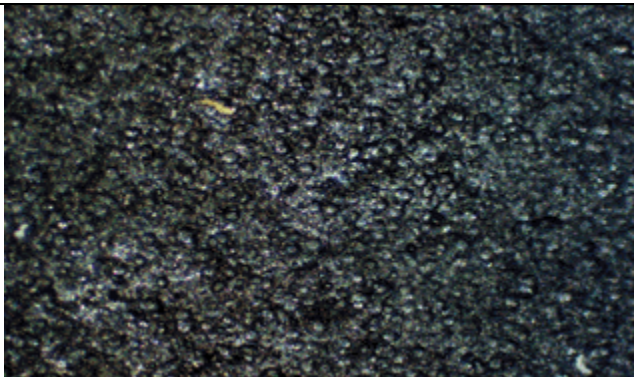
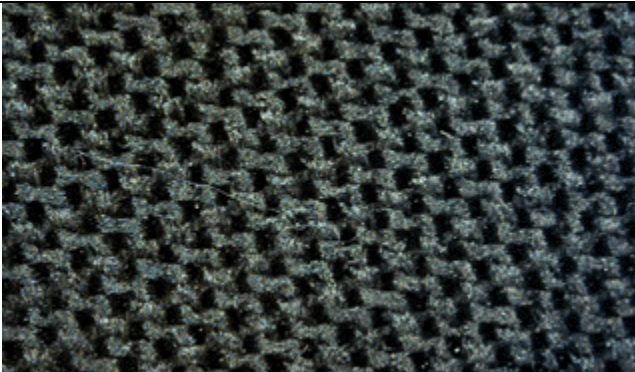
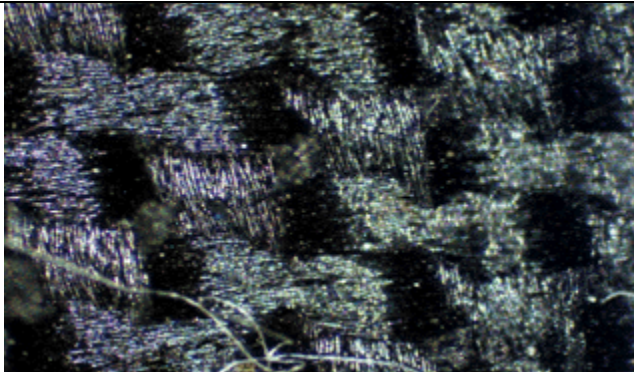
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 7.2.1 (Lab No. 059)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

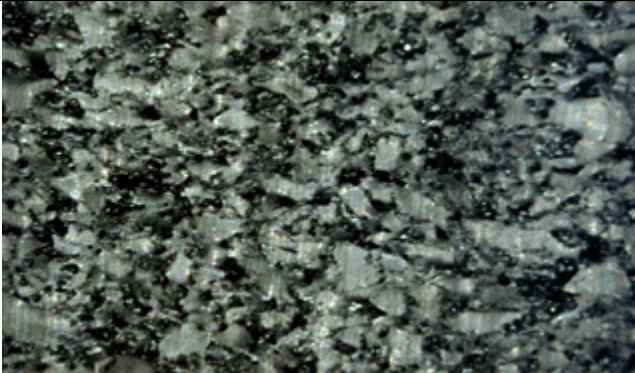
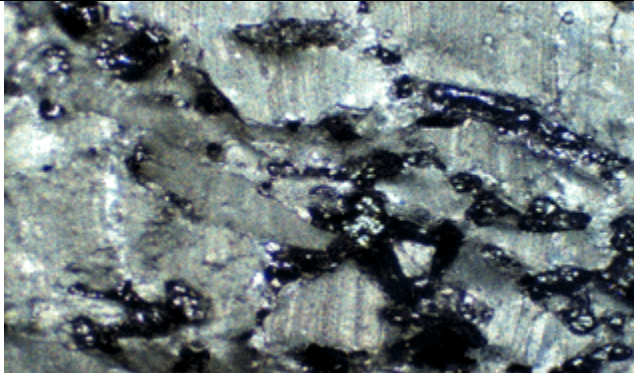
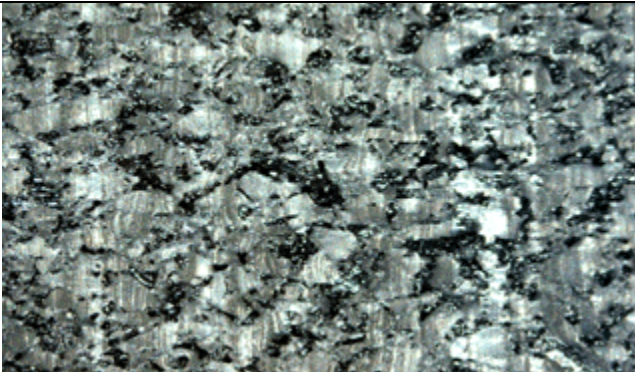
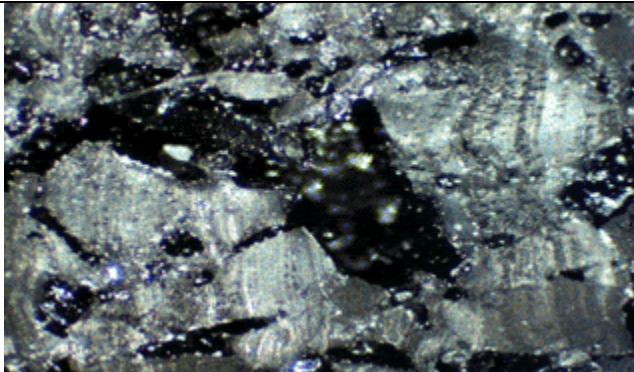
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 7.3.1 (Lab No. 046)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

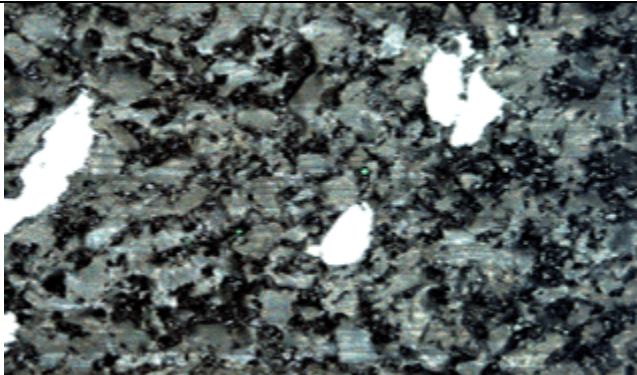

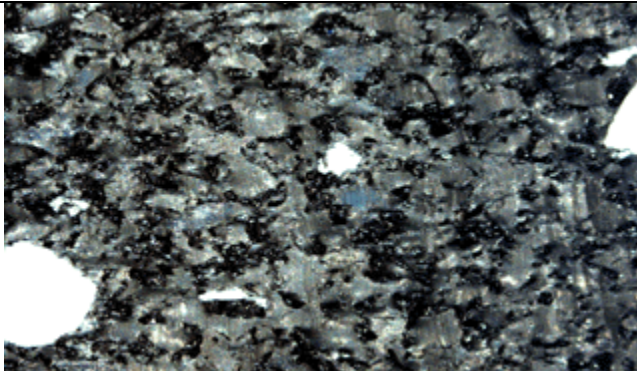
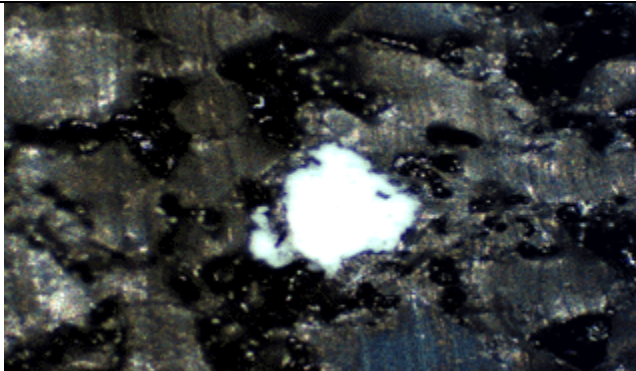
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 7.4.1 (Lab No. 056)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

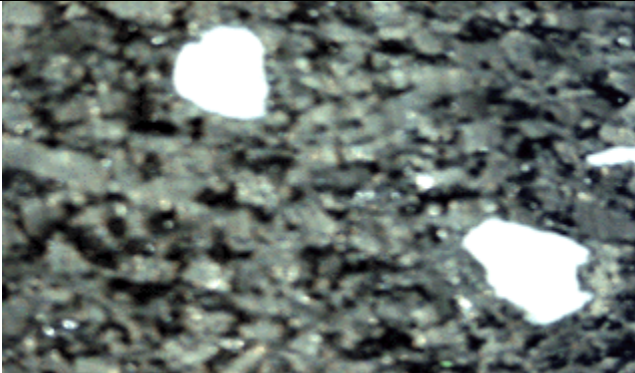
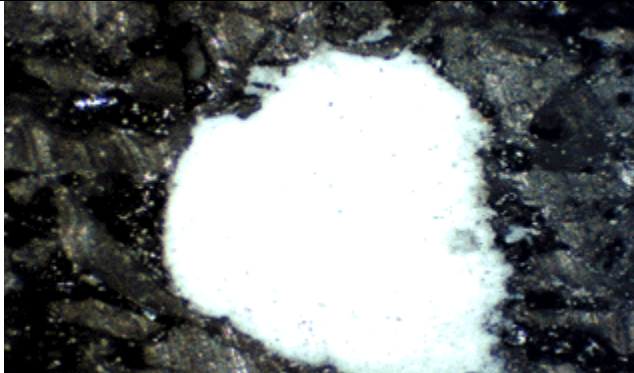
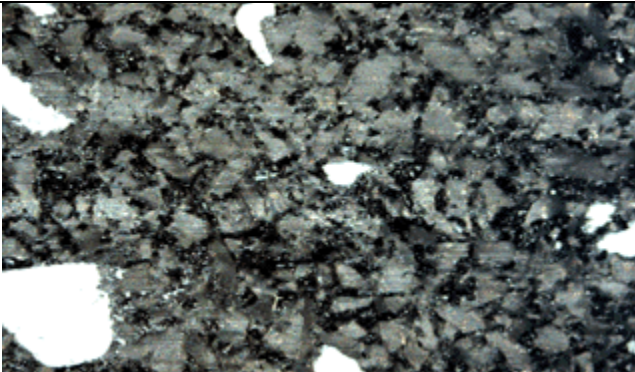
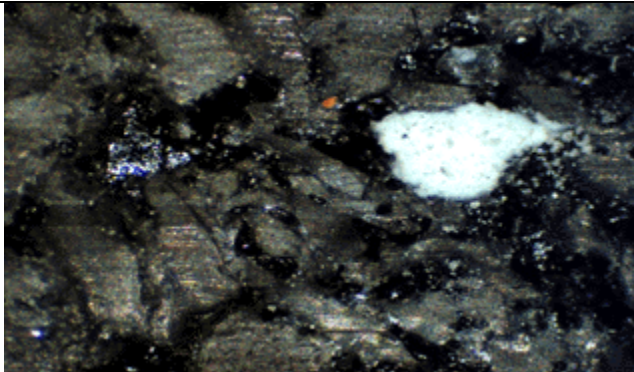
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 8.1.1 (Lab No. 067)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

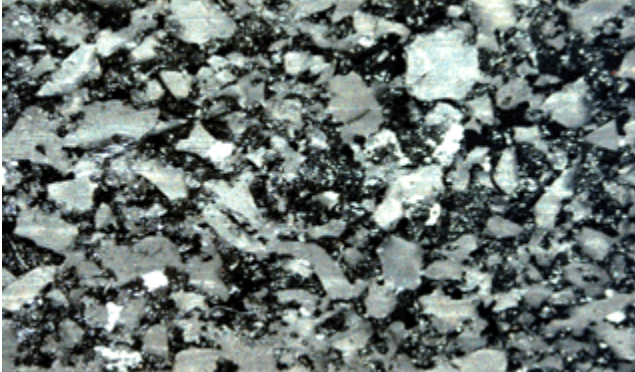
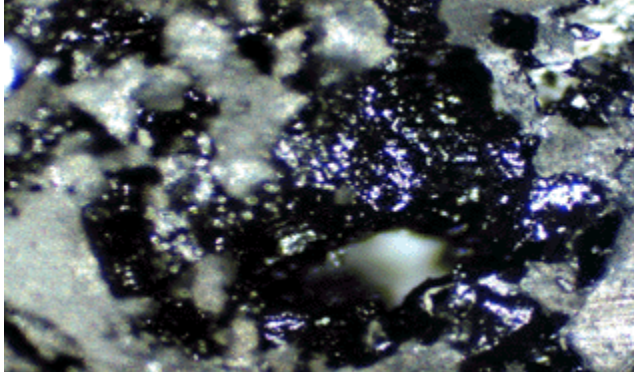
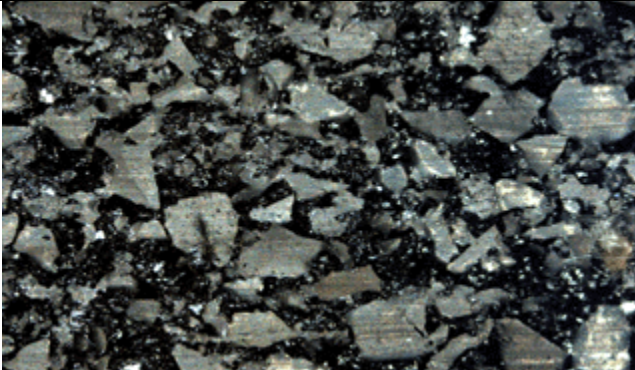
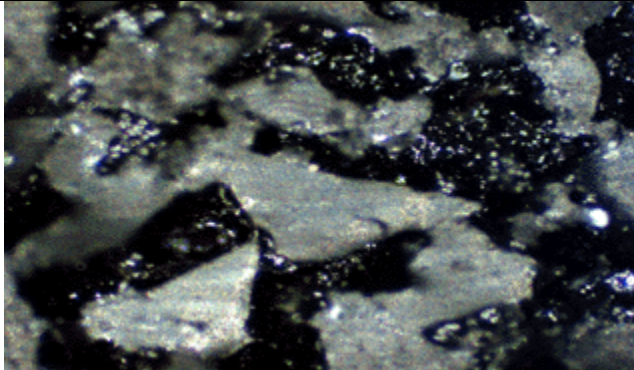
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 8.2.1 (Lab No. 012)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

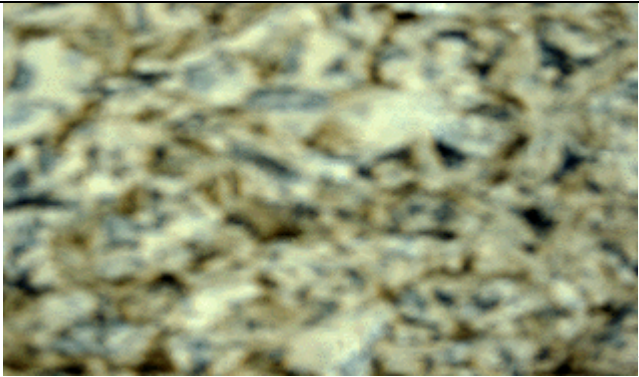
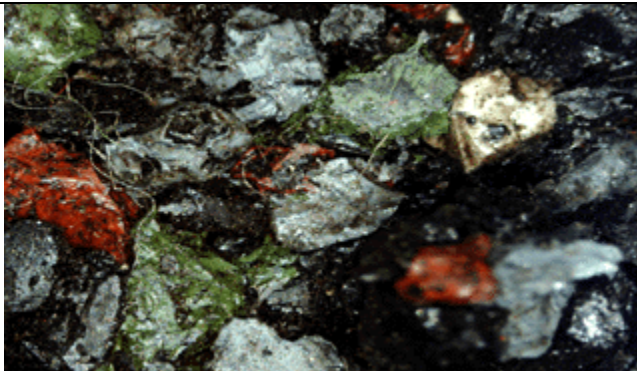
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 8.2.3 (Lab No. 066)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

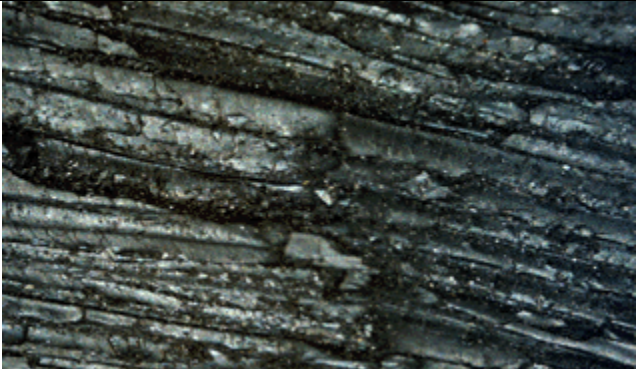
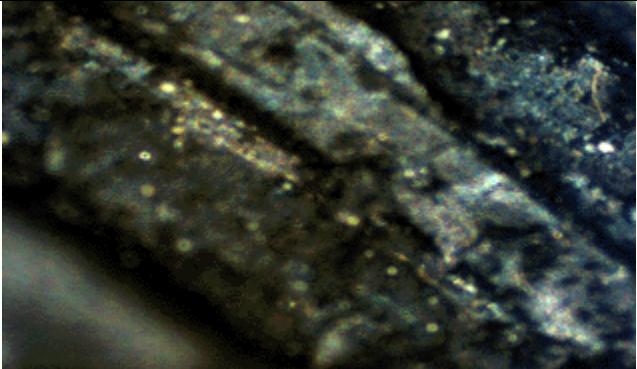
Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 8.3.1 (Lab No. 068)			
	Magnification 10x		Magnification 40x	
Top View				
Bottom View				

Tire-Derived Rubber Flooring Chemical Emissions Study

	Product No. 9.1.1 (Lab No. 042)	
	Magnification 10x	Magnification 40x
Top View		NA
Bottom View		NA

*: magnification was set at 6.3x.

Buffing (Lab No. 028)	
Magnification 10x	Magnification 40x
	

Appendix D. Laboratory Data for Products Tested in Study

This page intentionally left blank.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 1.1.1.A Percent TDR: 61-70% Use: Floor Manufacture Date: 10/10/2005
 Thickness (mm): 10 Product Form: Tile, Layered Conditioning Start: 10/28/2005
 Duplicate: YES Size: 24"x24" Application: Sport Color: Dark blue Flec: Blue, Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	28	26	20	9	25	14	11	10			< 3
Aniline (62-53-3) TP	56	43							20		7
Acetone (67-64-1) *H	35	36	37		45	25	20	18			< 4
Benzothiazole (95-16-9) *	410	420	210		258	145	113	100	140		130
Carbon disulfide (75-15-0) *TP	15	15	15		18	10	8	7	3		3
Cyclohexanone (108-94-1) *	16	15	< 14		< 17	< 10	< 8	< 7	8		6
n-Decane (124-18-5) *	22	18	< 14		< 17	< 10	< 8	< 7	< 3		6
4-Ethenylcyclohexene (100-40-3)	24	21							12		5
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	1		< 1
1-Ethyl-4-methylbenzene (622-96-8) *	24	19	< 14		< 17	< 10	< 8	< 7	9		5
N,N-dimethyl-Formamide (68-12-2) *T	16	14	7		9	5	4	3	9		< 1
Cyclic HC (rt: 27.8; 27.9)	81	97	39		48	27	21	19			
Indene (95-13-6) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	3		4
Methyl Isobutyl Ketone (108-10-1) *T	72	63	29		36	20	16	14	45		31
Naphthalene (91-20-3) *TP	17	14	< 6	9	< 7	< 4	< 3	< 3	8		64
n-Nonane (111-84-2) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	4		< 3
4-Phenylcyclohexene (4994-16-5) *	17	16									
Styrene (100-42-5) *T	14	12	7	900	9	5	4	3	7		4

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
 H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Toluene (108-88-3) *TP	11	8	< 6	300	< 7	< 4	< 3	< 3	8	3
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	< 14	< 14		< 17	< 10	< 8	< 7	3	< 3
Trimethylsilanol (1066-40-6)	27	38	23		28	16	12	11	10	18
n-Undecane (1120-21-4) *	46	38	18		22	12	10	9	18	17
o-Xylene (95-47-6) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	2	< 1
m/p-Xylene (106-42-3/108-38-3) *T	9	7	< 6	700	< 7	< 4	< 3	< 3	5	3
Unidentified (rt: 9.9)	400	340	190		233	131	102	91		
Sum-VOC	1,380	1,290	645		791	444	347	307	367	335

- End of Data For Product Number: 1.1.1.A -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 1.1.1.B Percent TDR: 61-70% Use: Floor Manufacture Date: 10/10/2005
 Thickness (mm): 10 Product Form: Tile, Layered Conditioning Start: 10/28/2005
 Duplicate: YES Size: 24"x24" Application: Sport Color: Dark blue Flec: Blue, Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	24	16	16	9	20	11	9	8			< 3
Aniline (62-53-3) TP	54	39	15		18	10	8	7	17		
Acetone (67-64-1) *H	32	25	36		44	25	19	17			< 4
Benzothiazole (95-16-9) *	390	350	200		245	138	107	95	120		60
Carbon disulfide (75-15-0) *TP	15	15	15		18	10	8	7	3		3
Cyclohexanone (108-94-1) *	16	< 14	< 14		< 17	< 10	< 8	< 7	8		< 3
n-Decane (124-18-5) *	< 14	15	< 14		< 17	< 10	< 8	< 7	< 3		< 3
4-Ethenylcyclohexene (100-40-3)	24	17							11		
1-Ethyl-4-methylbenzene (622-96-8) *	22	15	< 14		< 17	< 10	< 8	< 7	8		< 3
N,N-dimethyl-Formamide (68-12-2) *T	20	14	7		9	5	4	3	9		< 1
Cyclic HC (rt: 27.8; 27.9)	86	64	37		45	25	20	18			
Methyl Isobutyl Ketone (108-10-1) *T	62	53	21		26	14	11	10	38		14
Naphthalene (91-20-3) *TP	11	12	< 6	9	< 7	< 4	< 3	< 3	6		10
n-Nonane (111-84-2) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	3		< 3
4-Phenylcyclohexene (4994-16-5) *	13	14							5		
Styrene (100-42-5) *T	14	10	7	900	8	5	4	3	6		2
Toluene (108-88-3) *TP	9	7	< 6	300	< 7	< 4	< 3	< 3	6		< 1
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	< 14	< 14		< 17	< 10	< 8	< 7	3		< 3

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
 H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Trimethylsilanol (1066-40-6)	37		17		21	12	9	8	21	18
n-Undecane (1120-21-4) *	44	35	16		20	11	9	8	14	7
m/p-Xylene (106-42-3/108-38-3) *T	8	< 6	< 6	700	< 7	< 4	< 3	< 3	5	< 1
o-Xylene (95-47-6) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	1	< 1
Unidentified (rt: 9.9)	390		180		221	124	97	86		
Sum-VOC	1,306	741	607		745	418	326	289	474	125

- End of Data For Product Number: 1.1.1.B -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 1.2.1	Percent TDR: 61-70%	Use: Floor	Manufacture Date: 12/01/2005
	Thickness (mm): 10	Product Form: Tile, Layered	Conditioning Start 12/23/2005
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	20	15	15	9	18	10	8	7			
Acetone (67-64-1) *H	22	< 20	< 20		< 25	< 14	< 11	< 10			
Benzothiazole (95-16-9) *	200	170	150		184	103	81	71	26		
Carbon disulfide (75-15-0) *TP	< 6	16	< 6		< 7	< 4	< 3	< 3	4		
Cyclic HC (rt: 14.1)	80	71	77		94	53	41	37			
Cyclic HC (rt: 27.8; 27.9)	39	33	32		39	22	17	15			
Cyclic HC (rt: 32.9)	68	46	43		53	30	23	20			
Isopropyl Alcohol (67-63-0) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	2		
Methyl Isobutyl Ketone (108-10-1) *T	31	31	31		38	21	17	15	13		
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	12		
Styrene (100-42-5) *T	20	19	17	900	21	12	9	8	4		
Trimethylsilanol (1066-40-6)	19	22	20		25	14	11	10	17		
Unidentified (rt: 9.9)	30		39		48	27	21	19			
Sum-VOC	530	424	425		521	293	228	203	79		

- End of Data For Product Number: 1.2.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 2.1.1	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 10/12/2005
	Thickness (mm): 60	Product Form: Pavers, Homogeneous	Conditioning Start 11/11/2005
Duplicate: NO	Size: 22"x44"	Application: Play	Color: Blue / Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	22	29	47	9	58	32	25	22	5	8	
Acetone (67-64-1) *H	22	21	30		37	21	16	14	5	7	
Cyclic Alcohol (rt: 14.4)	41	38	45		55	31	24	21			
Benzothiazole (95-16-9) *	380	350	340		417	234	183	162	140	73	160
Carbon disulfide (75-15-0) *TP	< 6	< 6	17		21	12	9	8	4	< 1	< 1
Cyclohexanone (108-94-1) *	110	90	110		135	76	59	52	42	14	23
n-Decane (124-18-5) *	25	22	21		26	14	11	10	< 3	< 3	< 3
Ethylbenzene (100-41-4) *TP	42	36	43	2,000	53	30	23	20	19	3	< 1
1-Ethyl-2-methylbenzene (611-14-3) *	16	< 14	< 14		< 17	< 10	< 8	< 7	11	< 3	4
1-Ethyl-4-methylbenzene (622-96-8) *	51	47	46		56	32	25	22	27	9	11
Formaldehyde (50-00-0) *HTP	28	25	29	33	36	20	16	14		6	7
Branched HC (rt: 11.6)	55	39	51		63	35	27	24			
Branched HC (rt: 11.25)	110	69	91		112	63	49	43			
Branched HC (rt: 12.6)	660	450	540		662	372	290	257			
Branched HC (rt: 14.9)	120	110	110		135	76	59	52			
Methyl Isobutyl Ketone (108-10-1) *T	290	240	280		343	193	150	133	88	30	46
1-Methyl-2-pyrrolidinone (872-50-4) *P	110	96	100		123	69	54	48	36	15	43
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	10	10	10

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

n-Nonane (111-84-2) *	< 14	16	18		22	12	10	9	4	< 3	< 3
Pentadecane (629-62-9)	21	18	19		23	13	10	9			6
Propionaldehyde (123-38-6) *HT	26	25	51		63	35	27	24		5	7
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	3	< 1	< 1
Toluene (108-88-3) *TP	29	22	26	300	32	18	14	12	7	< 1	< 1
1,2,4-Trimethylbenzene (95-63-6) *TP	45	39	42		52	29	23	20	21	10	11
1,3,5-Trimethylbenzene (108-67-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	7	< 3	3
Trimethylsilanol (1066-40-6)	33		41		50	28	22	20	21	8	9
n-Undecane (1120-21-4) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	12	4	4
o-Xylene (95-47-6) *T	52	47	49	700	60	34	26	23	20	6	4
m/p-Xylene (106-42-3/108-38-3) *T	100	96	110	700	135	76	59	52	< 1	12	8
Sum-VOC	3,121	2,470	2,759		3,384	1,899	1,483	1,315	1,307	428	616

- End of Data For Product Number: 2.1.1 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 2.1.2	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 10/13/2005
	Thickness (mm): 60	Product Form: Pavers, Homogeneous	Conditioning Start 11/11/2005
Duplicate: NO	Size: 22"x44"	Application: Play	Color: Blue / Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	29	27	40	9	49	28	21	19	4	5	
Acetone (67-64-1) *H	40	32	31		38	21	17	15	6	7	
Cyclic Alcohol (rt: 14.4)	36	38	43		53	30	23	20			
Benzothiazole (95-16-9) *	350	350	350		429	241	188	167	110	20	60
Carbon disulfide (75-15-0) *TP	< 6	< 6	< 6		< 7	< 4	< 3	< 3	4	4	4
Cyclohexanone (108-94-1) *	86	82	97		119	67	52	46	38	7	10
n-Decane (124-18-5) *	20	22	22		27	15	12	10	< 3	< 3	3
Ethylbenzene (100-41-4) *TP	33	32	38	2,000	47	26	20	18	15	< 1	< 1
1-Ethyl-2-methylbenzene (611-14-3) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	7	< 3	< 3
1-Ethyl-4-methylbenzene (622-96-8) *	37	34	35		43	24	19	17	18	< 3	4
Formaldehyde (50-00-0) *HTP	37	25	28	33	34	19	15	13	3	4	
Branched HC (rt: 11.25)	88	110	100		123	69	54	48			
Branched HC (rt: 11.6)	42	50	49		60	34	26	23			
Branched HC (rt: 12.6)	550	720	620		760	427	333	295			
Isopropyl Alcohol (67-63-0) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	2	3	3
Methyl Isobutyl Ketone (108-10-1) *T	270	280	320		392	220	172	152	78	15	20
1-Methyl-2-pyrrolidinone (872-50-4) *P	69	81	79		97	54	42	38	24	< 1	< 1
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	89	9	80

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Propionaldehyde (123-38-6) *HT	32	26	30		37	21	16	14		< 5	< 5
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	2	< 1	< 1
Toluene (108-88-3) *TP	25	26	30	300	37	21	16	14	6	< 1	< 1
1,2,4-Trimethylbenzene (95-63-6) *TP	32	30	33		40	23	18	16	16	4	4
1,3,5-Trimethylbenzene (108-67-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	5	< 3	< 3
Trimethylsilanol (1066-40-6)	30	46	51		63	35	27	24	10	16	20
n-Undecane (1120-21-4) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	7	< 3	< 3
m/p-Xylene (106-42-3/108-38-3) *T	91	92	100	700	123	69	54	48	33	6	4
o-Xylene (95-47-6) *T	42	41	46	700	56	32	25	22	17	2	2
Sum-VOC	2,491	2,958	3,007		3,687	2,070	1,616	1,433	1,069	280	371

- End of Data For Product Number: 2.1.2 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.1.1.A	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 10/03/2005
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 11/04/2005
Duplicate: YES	Size: 38"x38"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	31	< 14	17	9	21	12	9	8	4		3
Acetone (67-64-1) *H	21	23	25		31	17	13	12	< 4		< 4
Benzothiazole (95-16-9) *	150	120	130		159	89	70	62	92	58	120
Carbon disulfide (75-15-0) *TP	15	15	15		18	10	8	7	3	3	3
Cyclohexanone (108-94-1) *	16	< 14	< 14		< 17	< 10	< 8	< 7	19	5	7
Methyl Isobutyl Ketone (108-10-1) *T	100	76	65		80	45	35	31	68	9	8
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	3	< 1	< 1
Sum-VOC	337	261	266		326	183	143	127	207	77	147

- End of Data For Product Number: 3.1.1.A -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.1.1.B	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 10/03/2005
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 11/04/2005
Duplicate: YES	Size: 38"x38"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	36	23	17	9	21	12	9	8	< 3		4
Acetone (67-64-1) *H	23	29	29		36	20	16	14	< 4		< 4
Benzothiazole (95-16-9) *	170	130	120		147	83	64	57	61	20	38
Carbon disulfide (75-15-0) *TP	15	15	15		18	10	8	7	3	3	3
Cyclohexanone (108-94-1) *	16	< 14	< 14		< 17	< 10	< 8	< 7	13	< 3	< 3
Methyl Isobutyl Ketone (108-10-1) *T	91	67	58		71	40	31	28	51	3	3
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	2	< 1	< 1
Sum-VOC	357	278	250		306	172	134	119	136	29	54

- End of Data For Product Number: 3.1.1.B -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.1.2	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 08/24/2005
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 11/18/2005
Duplicate: NO	Size: 38"x38"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	22	26	< 14	9	< 17	< 10	< 8	< 7		4	4
Acetone (67-64-1) *H	36	47	< 20		< 25	< 14	< 11	< 10		4	12
Benzothiazole (95-16-9) *	340	300	270		331	186	145	129	87	82	110
Carbon disulfide (75-15-0) *TP	15	15	15		18	10	8	7	3	3	< 1
Cyclohexanone (108-94-1) *	20	16	< 14		< 17	< 10	< 8	< 7	8	5	< 3
Methyl Isobutyl Ketone (108-10-1) *T	310	270	230		282	158	124	110	66	16	< 3
Sum-VOC	752	679	532		653	366	286	254	167	116	137

- End of Data For Product Number: 3.1.2 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.1.3	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 02/15/2006
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 03/03/2006
Duplicate: NO	Size: 38"x38"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Aliphatic Alcohol (rt: 20.8)	100										
Benzothiazole (95-16-9) *	1,200	840	720		883	496	387	343	76	18	
Butylated Hydroxytoluene (128-37-0)	94	140	65		80	45	35	31	100	15	
Chlorobenzene (108-90-7) *T	72	76	54		66	37	29	26	< 1	< 1	
Cyclohexanone (108-94-1) *	110	110	62		76	43	33	30	< 3	< 3	
Decanal (112-31-2) *	< 14	< 14	20		25	14	11	10	< 3	< 3	
n-Decane (124-18-5) *	22	22	< 14		< 17	< 10	< 8	< 7	< 3	< 3	
Ethylbenzene (100-41-4) *TP	< 6	24	19	2,000	23	13	10	9	< 1	< 1	
Branched HC (rt: 21.1)	78	83									
Cyclic HC (rt: 28.8)	130										
Methyl Isobutyl Ketone (108-10-1) *T	200	190	120		147	83	64	57	< 3	< 3	
Naphthalene (91-20-3) *TP	11	12	10	9	12	7	5	5	2	1	
Phenol (108-95-2) *T	< 6	7	7	200	9	5	4	4	< 1	< 1	
1,2,4-Trimethylbenzene (95-63-6) *TP	17	19	< 14		< 17	< 10	< 8	< 7	< 3	< 3	
n-Undecane (1120-21-4) *	65	65	16		20	11	9	8	< 3	< 3	
m/p-Xylene (106-42-3/108-38-3) *T	23	23	19	700	23	13	10	9	< 1	< 1	
Sum-VOC	2,180	1,950	1,220		1,496	840	656	581	206	87	

- End of Data For Product Number: 3.1.3 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.1.4	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 02/15/2006
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 03/03/2006
Duplicate: NO	Size: 38"x38"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Aliphatic Alcohol (rt: 20.8)	150										
Benzothiazole (95-16-9) *	200	660	340		417	234	183	162	180	56	
2-Butanone (78-93-3) *	15	< 6	< 6		< 7	< 4	< 3	< 3	< 1	< 1	
Cyclohexanone (108-94-1) *	160	61	48		59	33	26	23	9	14	
Chlorobenzene (108-90-7) *T	89	44	27		33	19	15	13	2	< 1	
Decanal (112-31-2) *	15	< 14	19		23	13	10	9	< 3	< 3	
2-Ethoxyethyl Acetate (111-15-9) *TP	< 6	6	< 6	300	< 7	< 4	< 3	< 3	< 1	< 1	
Ethylbenzene (100-41-4) *TP	35	19	12	2,000	15	8	6	6	< 1	16	
Methyl Isobutyl Ketone (108-10-1) *T	340	130	85		104	59	46	41	7	8	
α-Methylstyrene (98-83-9) *	15	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	
Naphthalene (91-20-3) *TP	7	10	8	9	10	5	4	4	3	2	
Nonanal (124-19-6) *	< 14	< 14	44		54	30	24	21	< 3	< 3	
Octanal (124-13-0) *	< 14	< 14	41		50	28	22	20	< 3	< 3	
Phenol (108-95-2) *T	< 6	8	7	200	8	5	4	3	< 1	< 1	
Styrene (100-42-5) *T	11	< 6	< 6	900	< 7	< 4	< 3	< 3	< 1	< 1	
Toluene (108-88-3) *TP	35	< 6	< 6	300	< 7	< 4	< 3	< 3	< 1	< 1	
1,2,4-Trimethylbenzene (95-63-6) *TP	25	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	
n-Undecane (1120-21-4) *	49	16	50		61	34	27	24	3	< 3	

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

m/p-Xylene (106-42-3/108-38-3) *T	32	19	12	700	15	8	6	6	< 1	16
Sum-VOC	1,231	1,524	1,016		1,246	699	546	484	614	182

- End of Data For Product Number: 3.1.4 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.2.1	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 10/16/2005
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 11/18/2005
Duplicate: NO	Size: 38"x38"	Application: Sport	Color: Black Flec: Green

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	50	24	33	9	40	23	18	16	< 3		5
Acetone (67-64-1) *H	< 20	22	32		39	22	17	15	< 4		12
Benzothiazole (95-16-9) *	200	180	150		184	103	81	71	82	22	23
Carbon disulfide (75-15-0) *TP	15	15	15		18	10	8	7	3	3	< 1
Cyclohexanone (108-94-1) *	29	25	20		25	14	11	10	18	< 3	< 3
Methyl Isobutyl Ketone (108-10-1) *T	150	120	100		123	69	54	48	51	4	< 3
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	3	< 1	< 1
Sum-VOC	461	394	359		440	247	193	171	164	32	50

- End of Data For Product Number: 3.2.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.2.2.A	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 09/27/2005
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 11/25/2005
Duplicate: YES	Size: 38"x38"	Application: Sport	Color: Black Flec: Green

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	27	29	26	9	32	18	14	12		3	
Acetone (67-64-1) *H	34	37	55		67	38	30	26		< 4	
Benzothiazole (95-16-9) *	540	250	250		307	172	134	119	69	120	98
Carbon disulfide (75-15-0) *TP	16	15	15		18	10	8	7	3	3	< 1
Cyclohexanone (108-94-1) *	86	31	39		48	27	21	19	11	9	5
N,N-dimethyl-Formamide (68-12-2) *T	< 6	< 6	< 6		< 7	< 4	< 3	< 3	2	2	
Methyl Isobutyl Ketone (108-10-1) *T	390	160	180		221	124	97	86	38	10	4
Tetradecane (629-59-4)	19										
m/p-Xylene (106-42-3/108-38-3) *T	13	< 6	< 6	700	< 7	< 4	< 3	< 3	2	< 1	< 1
Sum-VOC	1,168	533	578		708	398	310	275	128	150	127

- End of Data For Product Number: 3.2.2.A -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 3.2.2.B	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 09/27/2005
	Thickness (mm): 6	Product Form: Tile, Homogeneous	Conditioning Start 11/25/2005
Duplicate: YES	Size: 38"x38"	Application: Sport	Color: Black Flec: Green

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	28	19	30	9	37	21	16	14		5	4
Acetone (67-64-1) *H	< 20	< 20	28		34	19	15	13		< 4	13
Benzene (71-43-2) *TP	< 6	< 6	< 6	60	< 7	< 4	< 3	< 3	< 1	< 1	1
Benzothiazole (95-16-9) *	530	240	200		245	138	107	95	56	32	20
Carbon disulfide (75-15-0) *TP	16	15	< 6		< 7	< 4	< 3	< 3	3	< 1	< 1
Cyclohexanone (108-94-1) *	79	27	33		40	23	18	16	10	< 3	< 3
Methyl Isobutyl Ketone (108-10-1) *T	390	150	170		208	117	91	81	42	3	< 3
Tetradecane (629-59-4)	16										
m/p-Xylene (106-42-3/108-38-3) *T	12	< 6	< 6	700	< 7	< 4	< 3	< 3	2	< 1	< 1
Sum-VOC	1,128	460	471		577	324	253	224	118	48	71

- End of Data For Product Number: 3.2.2.B -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 4.1.1	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 09/14/2005
	Thickness (mm): 25	Product Form: Pavers, Homogeneous	Conditioning Start 09/30/2005
Duplicate: NO	Size: 24"x24"	Application: Barn	Color: Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	29	< 19	42	9	52	29	23	20			
Acetone (67-64-1) *H	42	< 26	41		50	28	22	20			
Benzothiazole (95-16-9) *	150	140	92		113	63	49	44			
Cyclohexanone (108-94-1) *	350	450	270		331	186	145	129			
n-Decane (124-18-5) *	54	63	42		52	29	23	20			
Ethylbenzene (100-41-4) *TP	750	860	500	2,000	613	344	269	238			
Formaldehyde (50-00-0) *HTP	16	< 15	18	33	22	12	10	9			
Hexanal (66-25-1) *	68	59	37		45	25	20	18			
Methylene Chloride (75-09-2) *TP	70	66	54	400	66	37	29	26			
Methyl Isobutyl Ketone (108-10-1) *T	840	950	470		576	324	253	224			
n-Nonane (111-84-2) *	32	35	20		25	14	11	10			
n-Octane (111-65-9) *	29	28	< 19		< 23	< 13	< 10	< 9			
Pentanal (110-62-3) *	19	< 19	< 19		< 23	< 13	< 10	< 9			
Styrene (100-42-5) *T	24	28	18	900	22	12	10	9			
Toluene (108-88-3) *TP	1,400	1,400	990	300	1,214	681	532	472			
1,2,3-Trimethylbenzene (526-73-8) *	25	25	< 19		< 23	< 13	< 10	< 9			
1,2,4-Trimethylbenzene (95-63-6) *TP	56	62	41		50	28	22	20			
1,3,5-Trimethylbenzene (108-67-8) *	21	24	< 19		< 23	< 13	< 10	< 9			

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

n-Undecane (1120-21-4) *	22	23	< 19		< 23	< 13	< 10	< 9
m/p-Xylene (106-42-3/108-38-3) *T	3,100	3,500	2,200	700	2,698	1,514	1,182	1,048
o-Xylene (95-47-6) *T	1,100	1,300	800	700	981	551	430	381
Unidentified (rt: 38.8)	11,000	13,000	11,000		13,490	7,572	5,911	5,242
Sum-VOC	19,208	22,030	16,708		20,489	11,500	8,979	7,962

- End of Data For Product Number: 4.1.1 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 4.2.1	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 09/14/2005
	Thickness (mm): 25	Product Form: Tile, Homogeneous	Conditioning Start 10/07/2005
Duplicate: NO	Size: 24"x24"	Application: Play	Color: Green

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	25	31	28	9	34	19	15	13			
Acetone (67-64-1) *H	< 26	< 26	36		44	25	19	17			
Benzene (71-43-2) *TP	16	10	< 8	60	< 10	< 6	< 4	< 4			
Benzothiazole (95-16-9) *	150	130	140		172	96	75	67			
Cyclohexanone (108-94-1) *	640	560	510		625	351	274	243			
n-Decane (124-18-5) *	43	34	< 19		< 23	< 13	< 10	< 9			
Ethylbenzene (100-41-4) *TP	1,100	840	780	2,000	957	537	419	372			
Formaldehyde (50-00-0) *HTP	< 15	< 15	20	33	25	14	11	10			
Hexanal (66-25-1) *	87	64	57		70	39	31	27			
Methylene Chloride (75-09-2) *TP	98	45	39	400	48	27	21	19			
Methyl Isobutyl Ketone (108-10-1) *T	2,900	2,300	1,700		2,085	1,170	914	810			
Naphthalene (91-20-3) *TP	430	420	410	9	503	282	220	195			
n-Nonane (111-84-2) *	54	42	38		47	26	20	18			
n-Octane (111-65-9) *	44	30	27		33	19	15	13			
Pentanal (110-62-3) *	46	< 19	22		27	15	12	10			
Styrene (100-42-5) *T	44	35	33	900	40	23	18	16			
Toluene (108-88-3) *TP	2,800	1,500	1,900	300	2,330	1,308	1,021	905			
1,2,3-Trimethylbenzene (526-73-8) *	37	26	27		33	19	15	13			

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

1,2,4-Trimethylbenzene (95-63-6) *TP	100	80	72		88	50	39	34
1,3,5-Trimethylbenzene (108-67-8) *	36	28	26		32	18	14	12
n-Undecane (1120-21-4) *	32	27	26		32	18	14	12
o-Xylene (95-47-6) *T	2,200	1,700	1,600	700	1,962	1,101	860	762
m/p-Xylene (106-42-3/108-38-3) *T	3,800	3,100	2,900	700	3,556	1,996	1,558	1,382
Unidentified (rt: 38.8)	11,000	9,700	11,000		13,490	7,572	5,911	5,242
Sum-VOC	25,716	20,726	21,421		26,269	14,745	11,512	10,207

- End of Data For Product Number: 4.2.1 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 4.3.1	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 10/16/2005
	Thickness (mm): 25	Product Form: Tile, Homogeneous	Conditioning Start 12/16/2005
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	35	21	< 14	9	< 17	< 10	< 8	< 7	< 3	7	
Acetone (67-64-1) *H	26	< 20	< 20		< 25	< 14	< 11	< 10	< 4	16	
Benzothiazole (95-16-9) *	200	190	160		196	110	86	76	29	66	110
2-Butoxyethanol (111-76-2) *T	< 6	< 6	< 6		< 7	< 4	< 3	< 3	< 1	3	17
Cyclohexanone (108-94-1) *	44	30	21		26	14	11	10	5	5	24
Ethylbenzene (100-41-4) *TP	17	13	7	2,000	9	5	4	3	1	5	< 1
1-Ethyl-4-methylbenzene (622-96-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	6
Formaldehyde (50-00-0) *HTP	24	21	23	33	28	16	12	11	3	5	
Cyclic HC (rt: 23.0)	32										
Cyclic HC (rt: 24.8)	44										
Methylene Chloride (75-09-2) *TP	< 6	< 6	< 6	400	< 7	< 4	< 3	< 3	< 1	3	< 1
Methyl Isobutyl Ketone (108-10-1) *T	97	71	35		43	24	19	17	6	7	20
Naphthalene (91-20-3) *TP	27	< 6	16	9	20	11	9	8	4	< 1	< 1
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	11
n-Undecane (1120-21-4) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	11
m/p-Xylene (106-42-3/108-38-3) *T	51	40	24	700	29	17	13	11	5	5	5
o-Xylene (95-47-6) *T	14	9	< 6	700	< 7	< 4	< 3	< 3	< 1	< 1	2
Sum-VOC	633	406	295		362	203	158	141	56	136	227

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

- End of Data For Product Number: 4.3.1 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 5.1.1	Percent TDR: None	Use: Floor	Manufacture Date: 01/19/2006
	Thickness (mm): 10	Product Form: Tile, Layered	Conditioning Start 02/03/2006
Duplicate: NO	Size: 39"x39"	Application: Commercial	Color: Red

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	23	20	26	9	32	18	14	12	6		< 3
Acetone (67-64-1) *H	48	54	60		74	41	32	29	16		6
Benzothiazole (95-16-9) *	1,200	920	1,000		1,226	688	537	477	320		440
Butylated Hydroxytoluene (128-37-0)	1,700	1,200	1,200		1,472	826	645	572	110		
Butyraldehyde (123-73-9) *H	< 23	< 23	< 23		< 28	< 16	< 12	< 11	6		< 5
Cyclohexanone (108-94-1) *	66	58	38		47	26	20	18	27		33
Aromatic HC (rt: 32.6)	300	360	200		245	138	107	95			
Cyclic HC (rt: 13.2)	78										
Cyclic HC (rt: 20.2)	59	45									
Cyclic HC (rt: 28.8)	170	90	160		196	110	86	76			
Nonanal (124-19-6) *	26	< 14	< 14		< 17	< 10	< 8	< 7	< 3		< 3
Phenol (108-95-2) *T	53	36	24	200	29	17	13	11	25		3
a-Pinene (80-56-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	7		< 3
Styrene (100-42-5) *T	21	17	16	900	20	11	9	8	10		3
Toluene (108-88-3) *TP	40	32	29	300	36	20	16	14	20		4
o-Xylene (95-47-6) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	3		< 1
Sum-VOC	3,836	2,881	2,776		3,404	1,910	1,492	1,323	669		570

- End of Data For Product Number: 5.1.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 5.2.1	Percent TDR: None	Use: Floor	Manufacture Date: 01/18/2006
	Thickness (mm): 2	Product Form: Tile, Homogeneous	Conditioning Start 02/03/2006
Duplicate: NO	Size: 24"x24"	Application: Commercial	Color: Grey Flec: Grey & White

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	27	22	22	9	27	15	12	10	4		< 3
Acetone (67-64-1) *H	56	60	54		66	37	29	26	15		6
Benzene (71-43-2) *TP	< 6	< 6	< 6	60	< 7	< 4	< 3	< 3	< 1	1	1
Benzothiazole (95-16-9) *	360	370	380		466	262	204	181	89	85	220
Butylated Hydroxytoluene (128-37-0)	47	1,200	1,500		1,839	1,032	806	715	52	140	17
Butyraldehyde (123-73-9) *H	< 23	< 23	< 23		< 28	< 16	< 12	< 11	8		< 5
Cyclohexanone (108-94-1) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	18
Decanal (112-31-2) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	14	< 3	< 3
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	< 1	2	28
Formaldehyde (50-00-0) *HTP	< 12	< 12	< 12	33	< 15	< 8	< 6	< 6	3		< 2
Heptanal (111-71-7) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	4	< 3	< 3
Cyclic HC (rt: 28.8)	100	75	73		90	50	39	35			
Methyl Isobutyl Ketone (108-10-1) *T	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	6	8
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	1	2
Nonanal (124-19-6) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	29	9	5
Octanal (124-13-0) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	26	< 3	< 3
Phenol (108-95-2) *T	7	6	6	200	8	4	3	3	1	2	< 1
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	< 1	4	< 1

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Toluene (108-88-3) *TP	< 6	< 6	< 6	300	< 7	< 4	< 3	< 3	< 1	< 1	2
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	< 1	2	28
Sum-VOC	626	2,141	2,421		2,969	1,667	1,301	1,154	290	292	389

- End of Data For Product Number: 5.2.1 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.1.1 Percent TDR: 0-10% Use: Floor Manufacture Date: 12/12/2005
 Thickness (mm): 3 Product Form: Roll, Homogeneous Conditioning Start: 12/30/2005
 Duplicate: NO Size: 55"x49.2' Application: Sport Color: Multicolor Flec: Grey, White, Tan, &

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)					Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room		28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	< 14	16	9	20	11	9	8		< 3	5	
Acetone (67-64-1) *H	44	36	41		50	28	22	20		< 4	16	
Benzothiazole (95-16-9) *	15	< 14	< 14		< 17	< 10	< 8	< 7		< 3	< 3	
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3		< 1	9	< 1
Sum-VOC	77	53	78		96	54	42	37		4	390	

- End of Data For Product Number: 6.1.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
 H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.2.1.A Percent TDR: 0-10% Use: Floor Manufacture Date: 02/02/2006
 Thickness (mm): 3 Product Form: Roll, Homogeneous Conditioning Start: 02/10/2006
 Duplicate: YES Size: 48" wide Application: Commercial Color: Multicolor Flec: Orange, White, Tan

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	19	17	27	9	33	19	15	13	6	< 3	3
Acetone (67-64-1) *H	89	75	78		96	54	42	37	15	16	7
Acetophenone (98-86-2) *T	16	< 14	< 14		< 17	< 10	< 8	< 7	< 3		< 3
Cyclohexanone (108-94-1) *	< 14	< 14	110		135	76	59	52	< 3		< 3
Decanal (112-31-2) *	19	< 14	< 14		< 17	< 10	< 8	< 7	< 3		< 3
Ethylbenzene (100-41-4) *TP	< 6	< 6	75	2,000	92	52	40	36	< 1		3
Formaldehyde (50-00-0) *HTP	< 12	< 12	16	33	20	11	9	8	4	< 2	< 2
Aromatic HC (rt: 21.0)	150	150	95		117	65	51	45			
Aromatic HC (rt: 23.7)	120	120									
Aromatic HC (rt: 29.3)	140	120	78		96	54	42	37			
Aromatic HC (rt: 31.2)	920	890	660		809	454	355	315			
Aromatic HC (rt: 32.6)	120										
Cyclic HC (rt: 19.0)	190	150									
Methyl Isobutyl Ketone (108-10-1) *T	< 14	< 14	40		49	28	21	19	< 3		7
Naphthalene (91-20-3) *TP	< 6	< 6	10	9	12	7	5	5	1		3
Nonanal (124-19-6) *	26	< 14	15		18	10	8	7	7		< 3
Phenol (108-95-2) *T	6	< 6	< 6	200	< 7	< 4	< 3	< 3	< 1		< 1
1,1,1-Trichloroethane (71-55-6) *T	< 6	< 6	< 6	1,000	< 7	< 4	< 3	< 3	1		< 1

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
 H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

1,2,4-Trimethylbenzene (95-63-6) *TP	15	< 14	< 14		< 17	< 10	< 8	< 7	< 3		< 3
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	76	700	93	52	41	36	< 1		3
Sum-VOC	1,861	1,594	1,810		2,220	1,246	973	863	121	16	288

- End of Data For Product Number: 6.2.1.A -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.2.1.B Percent TDR: 0-10% Use: Floor Manufacture Date: 02/02/2006
 Thickness (mm): 3 Product Form: Roll, Homogeneous Conditioning Start: 02/10/2006
 Duplicate: YES Size: 48" wide Application: Commercial Color: Multicolor Flec: Orange, White, Tan

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	21	22	23	9	28	16	12	11		5	< 3
Acetophenone (98-86-2) *T	< 14	< 14	< 14		< 17	< 10	< 8	< 7	8		< 3
Acetone (67-64-1) *H	54	76	93		114	64	50	44		16	7
Butylated Hydroxytoluene (128-37-0)	150										
Decanal (112-31-2) *	< 14	15	< 14		< 17	< 10	< 8	< 7	< 3		< 3
Formaldehyde (50-00-0) *HTP	< 11	20	12	33	15	8	6	6		4	< 2
Aromatic HC (rt: 21.0)	130	110	72		88	50	39	34			
Aromatic HC (rt: 23.7)	170		87		107	60	47	41			
Aromatic HC (rt: 29.3)	610	120	95		117	65	51	45			
Aromatic HC (rt: 31.6)	400	580	380		466	262	204	181			
Aromatic HC (rt: 31.2)	500	730	510		625	351	274	243			
Aromatic HC (rt: 32.6)	200	67	67		82	46	36	32			
Cyclic HC (rt: 30.6)	340										
Naphthalene (91-20-3) *TP	< 6	6	< 6	9	< 7	< 4	< 3	< 3	1		1
Nonanal (124-19-6) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	11		< 3
Octanal (124-13-0) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	14		< 3
Phenol (108-95-2) *T	7	< 6	< 6	200	< 7	< 4	< 3	< 3	2		< 1
Propionaldehyde (123-38-6) *HT	45	< 23	< 23		< 28	< 16	< 12	< 11		< 5	< 5

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
 H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

1,2,4-Trimethylbenzene (95-63-6) *TP	20	< 14	< 14	< 17	< 10	< 8	< 7	4		< 3
Sum-VOC	2,701	2,084	1,449	1,777	997	779	690	251	25	188

- End of Data For Product Number: 6.2.1.B -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.3.1	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 12/11/2005
	Thickness (mm): 10	Product Form: Tile, Homogeneous	Conditioning Start 12/30/2005
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetone (67-64-1) *H	20	24	< 20		< 25	< 14	< 11	< 10	< 4		
Acetophenone (98-86-2) *T	260	250	200		245	138	107	95	130	17	
Aromatic Alcohol (rt: 22.6)	150	140	130		159	89	70	62			
Benzothiazole (95-16-9) *	190	180	200		245	138	107	95	67	210	
Carbon disulfide (75-15-0) *TP	< 6	< 6	16		20	11	9	8	4	< 1	
Cyclohexanone (108-94-1) *	30	26	27		33	19	15	13	16	11	
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	< 1	3	
Aromatic HC (rt: 21.5)	56	53	46		56	32	25	22			
Methylcyclohexane (108-87-2) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	4	< 3	
Methyl Isobutyl Ketone (108-10-1) *T	190	180	180		221	124	97	86	92	18	
α-Methylstyrene (98-83-9) *	23	20	20		25	14	11	10	12	< 3	
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	88	< 1
Propionaldehyde (123-38-6) *HT	23	32	< 23		< 28	< 16	< 12	< 11	< 5		
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	4	3	
Sum-VOC	953	912	870		1,067	599	467	414	339	534	

- End of Data For Product Number: 6.3.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.3.2	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 02/02/2006
	Thickness (mm): 10	Product Form: Tile, Homogeneous	Conditioning Start 02/24/2006
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	29	29	29	9	36	20	16	14	< 3	< 3	
Acetophenone (98-86-2) *T	78	40	26		32	18	14	12	< 3	< 3	
Acetone (67-64-1) *H	69	96	98		120	67	53	47	8	4	
Benzothiazole (95-16-9) *	480	430	560		687	385	301	267	230	59	
Butylated Hydroxytoluene (128-37-0)	98	91	150		184	103	81	71	22		
Butyraldehyde (123-73-9) *H	30	< 23	32		39	22	17	15	< 5	< 5	
Cyclohexanone (108-94-1) *	110	83	48		59	33	26	23	29	15	
Ethylbenzene (100-41-4) *TP	15	14	12	2,000	15	8	6	6	35	18	
Aromatic HC (rt: 22.1)	180	130	160		196	110	86	76			
Branched HC (rt: 21.1)	61	78	69		85	47	37	33			
Branched HC (rt: 24.5)	38	43	43		53	30	23	20			
Branched HC (rt: 25.9)	35										
Branched HC (rt: 25.2)	76	74	95		117	65	51	45			
Methyl Isobutyl Ketone (108-10-1) *T	210	180	150		184	103	81	71	16	7	
α-Methylstyrene (98-83-9) *	28	20	< 14		< 17	< 10	< 8	< 7	< 3	< 3	
Naphthalene (91-20-3) *TP	8	8	8	9	10	6	4	4	2	2	
Nonanal (124-19-6) *	31	46	< 14		< 17	< 10	< 8	< 7	< 3	4	
Phenol (108-95-2) *T	6	7	7	200	9	5	4	3	< 1	< 1	

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Toluene (108-88-3) *TP	< 6	7	< 6	300	< 7	< 4	< 3	< 3	3	< 1
n-Undecane (1120-21-4) *	32	33	< 14		< 17	< 10	< 8	< 7	< 3	< 3
m/p-Xylene (106-42-3/108-38-3) *T	14	14	12	700	15	8	6	6	35	18
Sum-VOC	1,692	1,470	1,655		2,029	1,139	889	789	514	182

- End of Data For Product Number: 6.3.2 -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.4.1	Percent TDR: None	Use: Floor	Manufacture Date: 12/14/2005
	Thickness (mm): 10	Product Form: Tile, Layered	Conditioning Start 01/13/2006
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Grey Flec: Silver & Tan

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	18	< 14	< 14	9	< 17	< 10	< 8	< 7	9		5
Acetone (67-64-1) *H	89	59	64		78	44	34	30	28		18
Benzothiazole (95-16-9) *	1,500	1,600	1,200		1,472	826	645	572	460	230	120
2-Butanone (78-93-3) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	< 1	2	< 1
Carbon disulfide (75-15-0) *TP	500	440	270		331	186	145	129	45	5	< 1
Formaldehyde (50-00-0) *HTP	< 12	< 12	< 12	33	< 15	< 8	< 6	< 6	3		< 2
N,N-dimethyl-Formamide (68-12-2) *T	< 6	8	< 6		< 7	< 4	< 3	< 3	5		
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	7	16	7
Styrene (100-42-5) *T	29	32	23	900	28	16	12	11	10	6	3
Tert-butyl isothiocyanate (590-42-1)	30	34	27		33	19	15	13	12	11	
Toluene (108-88-3) *TP	13	14	9	300	11	6	5	4	4	3	1
Trimethylsilanol (1066-40-6)	33	30	17		21	12	9	8	16		9
Sum-VOC	2,222	2,222	1,613		1,979	1,111	867	769	608	317	189

- End of Data For Product Number: 6.4.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.5.1	Percent TDR: None	Use: Floor	Manufacture Date: 12/14/2005
	Thickness (mm): 3	Product Form: Tile, Homogeneous	Conditioning Start 01/13/2006
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Light Grey Flec: Tan & Brown

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	< 14	< 14	9	< 17	< 10	< 8	< 7	4		3
Benzothiazole (95-16-9) *	1,400	1,300	810		993	558	435	386	270	810	310
Carbon disulfide (75-15-0) *TP	23	22	17		21	12	9	8	< 1	< 1	< 1
Isopropyl Alcohol (67-63-0) *	33	38	20		25	14	11	10	5	< 1	< 1
a-Methylstyrene (98-83-9) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	3	< 3
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	66	10
Styrene (100-42-5) *T	28	30	25	900	31	17	13	12	7	24	6
Tert-butyl isothiocyanate (590-42-1)	18	18	16		20	11	9	8	5	19	
Toluene (108-88-3) *TP	< 6	6	< 6	300	< 7	< 4	< 3	< 3	< 1	4	< 1
Sum-VOC	1,507	1,554	892		1,094	614	479	425	318	1,158	467

- End of Data For Product Number: 6.5.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.6.1.A	Percent TDR: None	Use: Floor	Manufacture Date: 02/03/2006
	Thickness (mm): 10	Product Form: Tile, Layered	Conditioning Start 02/17/2006
Duplicate: YES	Size: 24"x24"	Application: Sport	Color: Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	33	45		9					4	< 3	
Acetone (67-64-1) *H	94	110							16	7	
Benzene (71-43-2) *TP	< 6	< 6	< 6	60	< 7	< 4	< 3	< 3	< 1	1	1
Benzothiazole (95-16-9) *	3,600	4,000	3,900		4,783	2,684	2,096	1,858	570	380	370
2-Butanone (78-93-3) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	1	< 1	< 1
Butylated Hydroxytoluene (128-37-0)	510		1,200		1,472	826	645	572	79		
Butyraldehyde (123-73-9) *H	< 23	35							< 5	< 5	
Carbon Disulfide (75-15-0) *TP	50	16	< 6		< 7	< 4	< 3	< 3	20	< 1	< 1
Cyclohexanone (108-94-1) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	7	19
n-Decane (124-18-5) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	13	< 3
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	< 1	9	24
1-Ethyl-4-methylbenzene (622-96-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	11	< 3
Formaldehyde (50-00-0) *HTP	< 12	21		33					< 2	< 2	
Cyclic HC (rt: 24.4)	180										
Cyclic HC (rt: 27.5)	160	150	160		196	110	86	76			
Cyclic HC (rt: 27.9)	160		150		184	103	81	71			
Cyclic HC (rt: 28.5)	160		180		221	124	97	86			
d-Limonene (5989-27-5) *	24	15	17		21	12	9	8	< 3	< 3	< 3

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Methyl Isobutyl Ketone (108-10-1) *T	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	21	8
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	6	2
n-Nonane (111-84-2) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	4	< 3
4-Phenylcyclohexene (4994-16-5) *	10	10	11		13	8	6	5	2	< 1	< 1
Phenol (108-95-2) *T	8	7	11	200	13	8	6	5	1	< 1	1
Styrene (100-42-5) *T	46	59	40	900	49	28	21	19	8	12	2
Toluene (108-88-3) *TP	90	77	88	300	108	61	47	42	18	12	5
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	15	14		17	10	8	7	< 3	9	< 3
1,3,5-Trimethylbenzene (108-67-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	11	< 3
n-Undecane (1120-21-4) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	18	< 3
o-Xylene (95-47-6) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	< 1	3	< 1
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	< 1	9	24
Sum-VOC	5,220	4,653	5,997		7,354	4,128	3,223	2,857	836	955	525

- End of Data For Product Number: 6.6.1.A -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.6.1.B	Percent TDR: None	Use: Floor	Manufacture Date: 02/03/2006
	Thickness (mm): 10	Product Form: Tile, Layered	Conditioning Start 02/17/2006
Duplicate: YES	Size: 24"x24"	Application: Sport	Color: Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	41	34	24	9	29	17	13	11	4	3	6
Acetone (67-64-1) *H	110	99	80		98	55	43	38	12	15	17
Benzothiazole (95-16-9) *	2,600	2,600	2,900		3,556	1,996	1,558	1,382	960	420	570
Butylated Hydroxytoluene (128-37-0)	1,000	240	980		1,202	675	527	467	66		
Butyraldehyde (123-73-9) *H	51	53	< 23		< 28	< 16	< 12	< 11	< 5	< 5	< 5
Carbon disulfide (75-15-0) *TP	< 6	< 6	45		55	31	24	21	3	< 1	< 1
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	3	27	< 1
1-Ethyl-4-methylbenzene (622-96-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	5	< 3	< 3
Aromatic HC (rt: 32.6)	250	230	300		368	206	161	143			
Branched HC (rt: 17.9)	95										
Cyclic HC (rt: 27.9)	93										
Cyclic HC (rt: 27.5)	100										
Cyclic HC (rt: 28.5)	110										
d-Limonene (5989-27-5) *	< 14	30	< 14		< 17	< 10	< 8	< 7	10	< 3	4
Methyl Isobutyl Ketone (108-10-1) *T	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	8	< 3
α-Methylstyrene (98-83-9) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	4	< 3	< 3
Styrene (100-42-5) *T	8	41	26	900	32	18	14	12	23	7	7
Tert-butyl isothiocyanate (590-42-1)	110	110	70		86	48	38	33	62		

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Toluene (108-88-3) *TP	< 6	83	53	300	65	36	28	25	51	21	13
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	18	< 14		< 17	< 10	< 8	< 7	8	< 3	< 3
1,3,5-Trimethylbenzene (108-67-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	5	< 3	< 3
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	2	27	< 1
Sum-VOC	4,568	4,611	4,635		5,684	3,190	2,491	2,209	1,358	678	664

- End of Data For Product Number: 6.6.1.B -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 6.7.1	Percent TDR: None	Use: Floor	Manufacture Date: 02/03/2006
	Thickness (mm): 3	Product Form: Tile, Homogeneous	Conditioning Start 02/24/2006
Duplicate: NO	Size: 24"x24"	Application: Sport	Color: Tan Flec: Grey & Tan

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	27	24	24	9	29	17	13	11	4	4	
Acetone (67-64-1) *H	70	69	67		82	46	36	32	7	< 4	
Benzothiazole (95-16-9) *	1,100	720	660		809	454	355	315	350	53	
Decanal (112-31-2) *	19	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	
Formaldehyde (50-00-0) *HTP	< 11	14	< 11	33	< 13	< 8	< 6	< 5	< 2	< 2	
Aromatic HC (rt: 27.9)	67										
Aromatic HC (rt: 32.6)	53	79	43		53	30	23	20			
Cyclic HC (rt: 27.5)	87										
Cyclic HC (rt: 27.1)	75										
Cyclic HC (rt: 30.3)	74	59									
α-Methylstyrene (98-83-9) *	17	22	27		33	19	15	13	5	< 3	
Nonanal (124-19-6) *	76	68	51		63	35	27	24	< 3	< 3	
Phenol (108-95-2) *T	8	6	6	200	7	4	3	3	< 1	< 1	
Styrene (100-42-5) *T	18	17	16	900	20	11	9	8	9	5	
Toluene (108-88-3) *TP	22	23	23	300	28	16	12	11	5	2	
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	17	21		26	14	11	10	7	4	
Sum-VOC	1,784	1,179	1,275		1,564	878	685	608	886	337	

- End of Data For Product Number: 6.7.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 7.1.1.A	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 09/22/2005
	Thickness (mm): 10	Product Form: Roll, Layered	Conditioning Start 10/24/2005
Duplicate: YES	Size: 48" wide (up to 800')	Application: Commercial	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	22	< 14	21	9	26	14	11	10	6	< 3	
Acetone (67-64-1) *H	38	33	100		123	69	54	48	9	5	
Benzene (71-43-2) *TP	27	18	56	60	69	39	30	27	9	13	4
Benzothiazole (95-16-9) *	830	740	880		1,079	606	473	419	270	310	200
Carbon disulfide (75-15-0) *TP	20	19	19		23	13	10	9	4	5	4
Cyclohexanone (108-94-1) *	93	84	180		221	124	97	86	38	40	25
N,N-dimethyl-Formamide (68-12-2) *T	17	11	41		50	28	22	20	6	6	3
Methyl Isobutyl Ketone (108-10-1) *T	140	120	360		441	248	193	172	61	64	35
1-Methyl-2-pyrrolidinone (872-50-4) *P	< 6	< 6	< 6		< 7	< 4	< 3	< 3	1	< 1	< 1
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	21	23	14
Styrene (100-42-5) *T	< 6	< 6	7	900	9	5	4	3	1	< 1	< 1
Toluene (108-88-3) *TP	7	6	29	300	36	20	16	14	4	4	< 1
m/p-Xylene (106-42-3/108-38-3) *T	130	120	150	700	184	103	81	71	39	42	28
Unidentified (rt: 11.5)	63	56	130		159	89	70	62			
Sum-VOC	1,398	1,245	2,062		2,529	1,419	1,108	983	462	554	325

- End of Data For Product Number: 7.1.1.A -

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 7.1.1.B	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 09/22/2005
	Thickness (mm): 10	Product Form: Roll, Layered	Conditioning Start 10/24/2005
Duplicate: YES	Size: 48" wide (up to 800')	Application: Commercial	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	20	17	38	9	47	26	20	18		4	< 3
Acetone (67-64-1) *H	42	35	76		93	52	41	36		9	< 4
Benzene (71-43-2) *TP	29	19	22	60	27	15	12	10	16		3
Benzothiazole (95-16-9) *	680	640	760		932	523	408	362	230		69
Carbon disulfide (75-15-0) *TP	18	18	17		21	12	9	8	7		4
Cyclohexanone (108-94-1) *	92	75	110		135	76	59	52	36		12
Formaldehyde (50-00-0) *HTP	< 11	< 11	13	33	16	9	7	6		< 2	< 2
N,N-dimethyl-Formamide (68-12-2) *T	15	< 6	19		23	13	10	9	8		< 1
Ketone (rt: 17.3)	39										
Methyl Isobutyl Ketone (108-10-1) *T	120	98	160		196	110	86	76	63		17
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	21	< 1	8
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	1		< 1
Toluene (108-88-3) *TP	8	< 6	10	300	12	7	5	5	4		< 1
m/p-Xylene (106-42-3/108-38-3) *T	120	110	140	700	172	96	75	67	39		18
Unidentified (rt: 11.5)	55	51	72		88	50	39	34			
Sum-VOC	1,249	1,111	1,493		1,831	1,028	803	712	442	14	136

- End of Data For Product Number: 7.1.1.B -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 7.2.1	Percent TDR: 81-90%	Use: Underlayment	Manufacture Date: 12/01/2005
	Thickness (mm): 3	Product Form: Panel, Layered	Conditioning Start 12/23/2005
Duplicate: NO	Size: 96"x48"	Application: Acoustic	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	< 14	< 14	9	< 17	< 10	< 8	< 7	< 3	6	
Acetone (67-64-1) *H	< 20	< 20	< 20		< 25	< 14	< 11	< 10	< 4	15	
Benzene (71-43-2) *TP	< 6	< 6	< 6	60	< 7	< 4	< 3	< 3	< 1	1	
Benzothiazole (95-16-9) *	710	700	670		822	461	360	319	290	250	
2-Butanone (78-93-3) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	< 1	1	
Carbon disulfide (75-15-0) *TP	< 6	17	16		20	11	9	8	< 1	< 1	
Cyclohexanone (108-94-1) *	79	84	70		86	48	38	33	34	< 3	
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	< 1	2	
Formaldehyde (50-00-0) *HTP	< 12	14	< 12	33	< 15	< 8	< 6	< 6	< 2	3	
N,N-dimethyl-Formamide (68-12-2) *T	16	14	11		13	8	6	5	14		
Methyl Isobutyl Ketone (108-10-1) *T	89	83	70		86	48	38	33	32	6	
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	< 1	4	
Tert-butyl isothiocyanate (590-42-1)	30	28	25		31	17	13	12	13		
m/p-Xylene (106-42-3/108-38-3) *T	72	69	63	700	77	43	34	30	28	2	
Sum-VOC	1,012	1,012	928		1,138	639	499	442	413	309	

- End of Data For Product Number: 7.2.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 7.3.1.A	Percent TDR: 81-90%	Use: Underlayment	Manufacture Date: 09/22/2005
	Thickness (mm): 3	Product Form: Panel, Layered	Conditioning Start 10/14/2005
Duplicate: YES	Size: 96"x48"	Application: Acoustic	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	24	< 14	26	9	32	18	14	12	3	6	< 3
Acetone (67-64-1) *H	27	21	30		37	21	16	14	< 4	6	< 4
Benzene (71-43-2) *TP	27	23	11	60	13	8	6	5	< 1	< 1	< 1
Benzothiazole (95-16-9) *	280	240	86		105	59	46	41	160	280	160
Cyclohexyl Isothiocyanate (1122-82-3)	88	80									
Cyclohexanone (108-94-1) *	350	320	97		119	67	52	46			
Decanal (112-31-2) *	60	49	< 14		< 17	< 10	< 8	< 7			
n-Decane (124-18-5) *	60	57	< 14		< 17	< 10	< 8	< 7	< 3	< 3	< 3
Ethylbenzene (100-41-4) *TP	27	25	8	2,000	10	6	4	4	< 1	2	< 1
N-(1,1-dimethylethyl)-Formamide	50	41									
Branched HC (rt: 16.9)	800	600	210		258	145	113	100			
Branched HC (rt: 28.5)	160	150	40		49	28	21	19			
Branched HC (rt: 29.1)	33	29									
Branched HC (rt: 29.3)	79	69									
Methyl Isobutyl Ketone (108-10-1) *T	690	620	190		233	131	102	91			
Styrene (100-42-5) *T	30	29	9	900	10	6	5	4	< 1	< 1	< 1
Tert-butyl isothiocyanate (590-42-1)	560	500	160		196	110	86	76	6	8	
Toluene (108-88-3) *TP	530	580	120	300	147	83	64	57	< 1	< 1	< 1

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

1,2,4-Trimethylbenzene (95-63-6) *TP	27	23	< 14		< 17	< 10	< 8	< 7	< 3	< 3	< 3
n-Undecane (1120-21-4) *	18	16	< 14		< 17	< 10	< 8	< 7	< 3	< 3	< 3
m/p-Xylene (106-42-3/108-38-3) *T	950	910	280	700	343	193	150	133	10	56	1
o-Xylene (95-47-6) *T	28	28	< 6	700	< 7	< 4	< 3	< 3	< 1	< 1	< 1
Sum-VOC	4,914	4,450	1,310		1,606	902	704	624	220	395	176

- End of Data For Product Number: 7.3.1.A -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 7.3.1.B	Percent TDR: 81-90%	Use: Underlayment	Manufacture Date: 09/22/2005
	Thickness (mm): 3	Product Form: Panel, Layered	Conditioning Start 10/14/2005
Duplicate: YES	Size: 96"x48"	Application: Acoustic	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	27	32	32	9	39	22	17	15	7	3	< 3
Acetone (67-64-1) *H	25	25	28		34	19	15	13	5	5	< 4
Benzene (71-43-2) *TP	29	22	10	60	12	7	5	5	< 1	< 1	< 1
Benzothiazole (95-16-9) *	230	230	93		114	64	50	44	110	220	60
Cyclohexanone (108-94-1) *	270	270	120		147	83	64	57			
Cyclohexyl Isothiocyanate (1122-82-3)	73	70									
Decanal (112-31-2) *	40	45	18		22	12	10	9			
n-Decane (124-18-5) *	55	53	< 14		< 17	< 10	< 8	< 7	< 3	< 3	< 3
Ethylbenzene (100-41-4) *TP	22	21	10	2,000	12	7	5	5	< 1	< 1	< 1
N-(1,1-dimethylethyl)-Formamide	37	33									
Branched HC (rt: 16.9)	620	580	290		356	200	156	138			
Branched HC (rt: 28.5)	150	140	50		61	34	27	24			
Branched HC (rt: 29.1)	30										
Branched HC (rt: 29.3)	65	65									
Methyl Isobutyl Ketone (108-10-1) *T	530	500	210		258	145	113	100			
Styrene (100-42-5) *T	26	25	< 6	900	< 7	< 4	< 3	< 3	< 1	< 1	< 1
Tert-butyl isothiocyanate (590-42-1)	430	410	180		221	124	97	86	51	6	
Toluene (108-88-3) *TP	560	600	140	300	172	96	75	67	< 1	< 1	< 1

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

1,2,4-Trimethylbenzene (95-63-6) *TP	24	21	< 14		< 17	< 10	< 8	< 7	< 3	< 3	< 3
n-Undecane (1120-21-4) *	16	15	< 14		< 17	< 10	< 8	< 7	< 3	< 3	< 3
o-Xylene (95-47-6) *T	24	23	< 6	700	< 7	< 4	< 3	< 3	< 1	< 1	< 1
m/p-Xylene (106-42-3/108-38-3) *T	850	810	330	700	405	227	177	157	7	7	< 1
Sum-VOC	4,152	4,019	1,551		1,902	1,068	834	739	202	273	69

- End of Data For Product Number: 7.3.1.B -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 7.4.1	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 12/01/2005
	Thickness (mm): 3	Product Form: Roll, Layered	Conditioning Start 12/16/2005
Duplicate: NO	Size: 48" x 25', 50', 75'	Application: Commercial	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)					Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room		28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	21	15	< 14	9	< 17	< 10	< 8	< 7		< 3	6	
Acetone (67-64-1) *H	< 20	< 20	< 20		< 25	< 14	< 11	< 10		< 4	13	
Benzene (71-43-2) *TP	< 6	< 6	< 6	60	< 7	< 4	< 3	< 3		< 1	1	< 1
Benzothiazole (95-16-9) *	820	770	370		454	255	199	176		270	69	200
Carbon disulfide (75-15-0) *TP	< 6	< 6	16		20	11	9	8		4	< 1	< 1
Cyclohexanone (108-94-1) *	100	94	75		92	52	40	36		34	5	4
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3		< 1	< 1	2
Formaldehyde (50-00-0) *HTP	< 11	< 11	< 11	33	< 13	< 8	< 6	< 5		3	3	
N,N-dimethyl-Formamide (68-12-2) *T	36	19	19		23	13	10	9		12		
Methyl Isobutyl Ketone (108-10-1) *T	150	110	88		108	61	47	42		28	< 3	5
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3		16		8
Tert-butyl isothiocyanate (590-42-1)	48	42	33		40	23	18	16		15		
Toluene (108-88-3) *TP	26	19	12	300	15	8	6	6		3	< 1	< 1
m/p-Xylene (106-42-3/108-38-3) *T	110	100	73	700	90	50	39	35		22	3	2
Sum-VOC	1,350	1,231	688		843	473	370	328		411	107	293

- End of Data For Product Number: 7.4.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 8.1.1	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 11/08/2005
	Thickness (mm): 10	Product Form: Roll, Homogeneous	Conditioning Start 12/02/2005
Duplicate: NO	Size: 50'x48"	Application: Sport	Color: Black

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	43	28	28	9	34	19	15	13	< 3		5
Acetone (67-64-1) *H	45	29	25		31	17	13	12	< 4		17
Benzothiazole (95-16-9) *	380	320	320		392	220	172	152	95	63	220
Carbon disulfide (75-15-0) *TP	< 6	< 6	< 6		< 7	< 4	< 3	< 3	4	4	< 1
Cyclohexanone (108-94-1) *	33	29	27		33	19	15	13	10	< 3	15
Formaldehyde (50-00-0) *HTP	15	< 11	< 11	33	< 13	< 8	< 6	< 5		< 2	3
Methyl Isobutyl Ketone (108-10-1) *T	58	47	36		44	25	19	17	9	4	9
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	< 1	10
Toluene (108-88-3) *TP	110	88	62	300	76	43	33	30	7	< 1	< 1
1,2,4-Trimethylbenzene (95-63-6) *TP	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	3
n-Undecane (1120-21-4) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	6
Sum-VOC	690	545	551		675	379	296	262	126	74	444

- End of Data For Product Number: 8.1.1 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 8.2.1 Percent TDR: 81-90% Use: Floor Manufacture Date: 08/22/2005
 Thickness (mm): 10 Product Form: Roll, Homogeneous Conditioning Start: 09/23/2005
 Duplicate: NO Size: 50'x48" Application: Sport Color: Black Flec: Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Benzothiazole (95-16-9) *	360	300	290		356	200	156	138	150		130
Cyclohexanone (108-94-1) *	310	200	170		208	117	91	81			
Decanal (112-31-2) *	190	140	140		172	96	75	67			
n-Decane (124-18-5) *	48	34	28		34	19	15	13	< 3		< 3
Ethylbenzene (100-41-4) *TP	16	12	10	2,000	12	7	5	5	< 1		< 1
Hexanal (66-25-1) *	21	< 19	< 19		< 23	< 13	< 10	< 9			
Branched HC (rt: 28.6)	460	290	310		380	213	167	148			
Methyl Isobutyl Ketone (108-10-1) *T	240	160	110		135	76	59	52			
Styrene (100-42-5) *T	69	48	39	900	48	27	21	19	< 1		< 1
Toluene (108-88-3) *TP	1,700	1,400	1,200	300	1,472	826	645	572	< 1		< 1
1,2,3-Trimethylbenzene (526-73-8) *	26	19	< 19		< 23	< 13	< 10	< 9			
1,2,4-Trimethylbenzene (95-63-6) *TP	55	36	28		34	19	15	13	< 3		< 3
n-Undecane (1120-21-4) *	63	45	37		45	25	20	18	< 3		< 3
o-Xylene (95-47-6) *T	20	15	13	700	16	9	7	6	< 1		< 1
m/p-Xylene (106-42-3/108-38-3) *T	80	56	45	700	55	31	24	21	< 1		< 1
Sum-VOC	3,684	2,789	2,469		3,027	1,699	1,327	1,176	175		142

- End of Data For Product Number: 8.2.1 -

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 8.2.2	Percent TDR: 81-90%	Use: Floor	Manufacture Date: 11/08/2005
	Thickness (mm): 10	Product Form: Roll, Homogeneous	Conditioning Start 12/02/2005
Duplicate: NO	Size: 50'x48"	Application: Sport	Color: Black Flec: Grey

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	20	32	21	9	26	14	11	10	< 3		5
Acetone (67-64-1) *H	< 20	31	36		44	25	19	17	6		15
Benzothiazole (95-16-9) *	390	470	480		589	330	258	229	73	160	240
Carbon disulfide (75-15-0) *TP	< 6	< 6	< 6		< 7	< 4	< 3	< 3	4	< 1	< 1
Cyclohexanone (108-94-1) *	32	40	32		39	22	17	15	5	5	< 3
Formaldehyde (50-00-0) *HTP	16	19	17	33	21	12	9	8		4	< 2
Methyl Isobutyl Ketone (108-10-1) *T	17	23	16		20	11	9	8	6	9	< 3
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	< 1	10
Toluene (108-88-3) *TP	17	17	< 6	300	< 7	< 4	< 3	< 3	< 1	< 1	< 1
1,1,1-Trichloroethane (71-55-6) *T	< 6	< 6	< 6	1,000	< 7	< 4	< 3	< 3	< 1	< 1	1
Sum-VOC	516	669	612		750	421	329	292	99	189	525

- End of Data For Product Number: 8.2.2 -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 8.3.1.A	Percent TDR: 81-90%	Use: Underlayment	Manufacture Date: 11/08/2005
	Thickness (mm): 2	Product Form: Roll, Homogeneous	Conditioning Start 12/09/2005
Duplicate: YES	Size: 30'x30"	Application: Acoustic	Color: Black Flec: White

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	21	22	9	27	15	12	10	4	4	5
Acetone (67-64-1) *H	< 20	< 20	< 20		< 25	< 14	< 11	< 10	< 4	< 4	16
Benzothiazole (95-16-9) *	170	240	150		184	103	81	71	48	75	70
Carbon disulfide (75-15-0) *TP	< 6	15	< 6		< 7	< 4	< 3	< 3	< 1	< 1	< 1
Formaldehyde (50-00-0) *HTP	17	< 11	< 11	33	< 13	< 8	< 6	< 5	7	3	3
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	< 1	8
Sum-VOC	208	277	173		212	119	93	82	61	92	183

- End of Data For Product Number: 8.3.1.A -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 8.3.1.B	Percent TDR: 81-90%	Use: Underlayment	Manufacture Date: 11/08/2005
	Thickness (mm): 2	Product Form: Roll, Homogeneous	Conditioning Start 12/09/2005
Duplicate: YES	Size: 30'x30"	Application: Acoustic	Color: Black Flec: White

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	18	23	9	28	16	12	11	4	3	
Benzothiazole (95-16-9) *	230	240	160		196	110	86	76	17	25	92
Cyclohexanone (108-94-1) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	< 3	4
Formaldehyde (50-00-0) *HTP	16	14	14	33	17	10	8	7	4	6	
Naphthalene (91-20-3) *TP	< 6	< 6	< 6	9	< 7	< 4	< 3	< 3	< 1	< 1	9
Sum-VOC	247	273	198		242	136	106	94	25	35	176

- End of Data For Product Number: 8.3.1.B -

- Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor. **H** indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
2. Results with "<" are below instrumental reporting limit.
3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
4. See Report for model descriptions.
5. See Report for comparability with short-term Emission Factors.
6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 9.1.1.A	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 01/10/2006
	Thickness (mm): 50	Product Form: Pavers, Layered	Conditioning Start 01/20/2006
Duplicate: YES	Size: 9" hexagon	Application: Barn	Color: Tan

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	< 14	19	9	23	13	10	9	9		< 3
Acetone (67-64-1) *H	26	< 20	< 20		< 25	< 14	< 11	< 10	19		17
Benzothiazole (95-16-9) *	650	520	610		748	420	328	291	130	130	400
2-Butanone (78-93-3) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	< 1	1	< 1
2-Butoxyethanol (111-76-2) *T	< 6	< 6	< 6		< 7	< 4	< 3	< 3	18	9	< 1
Cyclohexanone (108-94-1) *	55	41	45		55	31	24	21	10	13	36
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	2	2	34
Formaldehyde (50-00-0) *HTP	24	21	28	33	34	19	15	13	6		3
N,N-dimethyl-Formamide (68-12-2) *T	9	< 6	< 6		< 7	< 4	< 3	< 3			
Aromatic HC (rt: 20.7)	32										
Isopropyl Alcohol (67-63-0) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	1	< 1	< 1
Methyl Isobutyl Ketone (108-10-1) *T	180	130	99		121	68	53	47	22	29	42
Naphthalene (91-20-3) *TP	18	16	8	9	9	5	4	4	< 1	44	< 1
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	< 1	< 1	2
Tetrachloroethylene (127-18-4) *TP	< 6	< 6	< 6	35	< 7	< 4	< 3	< 3	2	2	< 1
Toluene (108-88-3) *TP	< 6	< 6	< 6	300	< 7	< 4	< 3	< 3	< 1	< 1	3
1,2,4-Trimethylbenzene (95-63-6) *TP	18	< 14	< 14		< 17	< 10	< 8	< 7	7	7	9
Trimethylsilanol (1066-40-6)	61	29	22		27	15	12	10			

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	2	2	34
Sum-VOC	1,093	782	865		1,060	595	465	412	248	441	618

- End of Data For Product Number: 9.1.1.A -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary

Tire-Derived Resilient Flooring VOC Emissions Study

Specimen Information

Product Number: 9.1.1.B	Percent TDR: 91-100%	Use: Outdoor	Manufacture Date: 01/10/2006
	Thickness (mm): 50	Product Form: Pavers, Layered	Conditioning Start 01/20/2006
Duplicate: YES	Size: 9" hexagon	Application: Barn	Color: Tan

Analyte (CAS Number) ^{1,6}	Short Term ² Emission Factors (µg/m ² hr)			Chronic ³ Reference Exposure Limits (µg/m ³)	Modeled Concentrations ⁴ (µg/m ³)				Long-Term ⁵ Emission Factors (µg/m ² hr)		
	11-Day	12-Day	14-Day		Daycare	Locker Room	State Office	Class-room	28-Day	60-Day	90-Day
Acetaldehyde (75-07-0) *HTP	< 14	15	21	9	26	14	11	10	5		7
Acetone (67-64-1) *H	27	36	< 20		< 25	< 14	< 11	< 10	15		18
Benzothiazole (95-16-9) *	510	340	420		515	289	226	200	25	300	130
2-Butanone (78-93-3) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	< 1	2	< 1
2-Butoxyethanol (111-76-2) *T	< 6	< 6	< 6		< 7	< 4	< 3	< 3	6	< 1	4
Carbon disulfide (75-15-0) *TP	< 6	< 6	15		18	10	8	7	< 1	< 1	< 1
Cyclohexanone (108-94-1) *	45	31	32		39	22	17	15	4	28	6
Ethylbenzene (100-41-4) *TP	< 6	< 6	< 6	2,000	< 7	< 4	< 3	< 3	< 1	4	< 1
1-Ethyl-4-methylbenzene (622-96-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	4	< 3
Formaldehyde (50-00-0) *HTP	21	26	20	33	25	14	11	10	4		7
Branched HC (rt: 25.7)	30										
Isopropyl Alcohol (67-63-0) *	< 6	< 6	< 6		< 7	< 4	< 3	< 3	< 1	1	< 1
Methyl Isobutyl Ketone (108-10-1) *T	130	79	76		93	52	41	36	10	71	14
Naphthalene (91-20-3) *TP	18	9	6	9	7	4	3	3	7	88	22
Styrene (100-42-5) *T	< 6	< 6	< 6	900	< 7	< 4	< 3	< 3	< 1	2	< 1
Tetrachloroethylene (127-18-4) *TP	< 6	< 6	< 6	35	< 7	< 4	< 3	< 3	< 1	5	< 1
1,2,4-Trimethylbenzene (95-63-6) *TP	15	< 14	< 14		< 17	< 10	< 8	< 7	< 3	20	< 3
1,3,5-Trimethylbenzene (108-67-8) *	< 14	< 14	< 14		< 17	< 10	< 8	< 7	< 3	4	< 3

Notes: 1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. T indicates a CARB Toxic Air Contaminant; P indicates a California Proposition 65 Chemical.

2. Results with "<" are below instrumental reporting limit.

3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>

4. See Report for model descriptions.

5. See Report for comparability with short-term Emission Factors.

6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Analytical Result Summary**Tire-Derived Resilient Flooring VOC Emissions Study**

Trimethylsilanol (1066-40-6)	23		22		27	15	12	10			
m/p-Xylene (106-42-3/108-38-3) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	< 1	4	< 1
o-Xylene (95-47-6) *T	< 6	< 6	< 6	700	< 7	< 4	< 3	< 3	< 1	2	< 1
Sum-VOC	848	549	623		764	429	335	297	144	1,157	295

- End of Data For Product Number: 9.1.1.B -

- Notes:
1. Compounds marked with * were quantitated against a standard curve of that chemical; otherwise, the chemical was quantitated using a Toluene TIC response factor.
H indicates that the compound was collected on a DNPH cartridge and analyzed by HPLC, otherwise the compound was collected on a Tenax tube and analyzed by TD-GC/MS. **T** indicates a CARB Toxic Air Contaminant; **P** indicates a California Proposition 65 Chemical.
 2. Results with "<" are below instrumental reporting limit.
 3. Chronic Reference Exposure Limit. Website: <http://www.oehha.ca.gov/air/allrels.html>
 4. See Report for model descriptions.
 5. See Report for comparability with short-term Emission Factors.
 6. Sum-VOC is the sum of each chemical detected above the reporting limit.

Appendix E. Indoor Air Reference Exposure Levels (iRELs)

- Ethylene glycol mono-N-butyl ether
- N-Methyl-3-pyrrolidinone
- Naphthalene
- 1, 2, 4-Trimethylbenzene

Disclaimer

The following documents are solely the product of the State of California Office of Environmental Health Hazard Assessment (OEHHA). Neither the Public Health Institute nor the California Department of Public Health has endorsed these documents.

Information on OEHHA and their RELs is available at the web site:
http://www.oehha.ca.gov/air/hot_spots/index.html

This page intentionally blank.

Indoor Air Reference Exposure Levels (iRELs)

Under the Hot Spots regulatory program, OEHHA develops chronic Reference Exposure Levels (cRELs), acute RELs, and more recently 8-hour RELs. The cRELs are designed to be air concentrations at or below which health effects would not be anticipated with 24 hour a day exposure for a significant fraction of a lifetime, even among sensitive members of the general population. Acute RELs are air concentrations at or below which health effects would not be anticipated even among sensitive members of the general population with infrequent 1-hour exposures. Recently, OEHHA has developed 8-hour RELs. Eight hour RELs are air concentrations at or below which health effects would not be anticipated with repeated 8-hour exposures for a significant fraction of a lifetime. Acute, chronic and 8-hour RELs are available for limited number of chemicals and a number of chemicals emitted by products used in indoor environments do not have RELs. The chronic RELs have been used to assess the health hazards from measured or modeled indoor air concentrations. Information on acute, chronic and 8-hour RELs can be found on OEHHA's website at www.oehha.ca.gov.

The State of California Office of Environmental Health Hazard Assessment (OEHHA), under an Interagency Agreement with the California Integrated Waste Management Board (now CalRecycle), developed Indoor Air Reference Exposure Levels or iRELs for four chemicals: a) ethylene glycol mono-n-butyl ether, b) n-methyl-3-pyrrolidinone, c) naphthalene, and d) 1,2,4-trimethylbenzene. The iRELs are air concentrations where health impacts would not be expected even in sensitive members of the general population, with repeated eight hour exposures for a significant fraction of a lifetime. These chemicals were emitted by tire-derived flooring, and except for naphthalene, there was no way to estimate their noncancer health impacts before the iRELs were developed. OEHHA had not yet begun to develop 8-hour RELs under the Hot Spots program. Unlike a number of chemicals that are emitted by tire-derived flooring, sufficient toxicological information was available to develop iREL values.

Exceeding the acute, chronic, 8-hour or iREL air concentration for the specified exposure durations does not necessarily mean that noncancer health impacts will occur, but the likelihood of health impacts increases. The science of toxicology and risk assessment advances over time, so if chronic RELs or 8-hour RELs for these chemicals are developed under the Hot Spots program in the future, it may be appropriate to consider using those values instead of the iRELs. Note, the RELs are not part of any regulatory program, and OEHHA does have any control over their voluntary use by interested parties or organizations.

The iREL and cREL values (in $\mu\text{g}/\text{m}^3$) for the four chemicals are as follows:

Chemical	iREL	cREL
Ethylene glycol mono-N-butyl ether	300	14,000
N-Methyl-3-pyrrolidinone	2000	--
Naphthalene	13	9
1, 2, 4-Trimethylbenzene	300	--

The indoor air concentrations that would result from a particular building material, such as tire-derived resilient flooring, can be estimated if the emission rates are known, and certain assumption about ventilation rate and room size are made. Determining emission rates over time was one of the goals of the *Tire-Derived Flooring Chemical Emissions Study*. The modeled estimated indoor air concentrations of chemicals can be compared with the iRELs or cRELS to see if they remain below a level where health effects would not be anticipated to occur even in sensitive members of the general population.

The only chemical for which the maximum modeled air concentration for a product in the study ($11 \mu\text{g}/\text{m}^3$) was close to the iREL or cREL value is naphthalene. This indicates there is potential for adverse health impacts from naphthalene exposure. However, the total uncertainty factor for both the iREL and the cREL is considerable. The concentrations of chemicals measured in this Study, including naphthalene, generally decline over time, so that exposure does not remain at the initial high levels measured in this study. Naphthalene, in addition to its noncancer health impacts, is also carcinogenic. The indoor exposure from off-gassing rubber flooring is likely to be quite small in comparison with overall individual lifetime exposure; however, it would be prudent to reduce naphthalene emissions from this product.

ETHYLENE GLYCOL MONO-N-BUTYL ETHER

(2-butoxyethanol; butoxyethanol; butyl cellosolve; ethylene glycol mono-n-butyl ether; butyl glycol)

CAS Registry Number: 111-76-2



I. Toxicity Summary

<i>8-Hour inhalation reference exposure level</i>	300 $\mu\text{g}/\text{m}^3$ (60 ppb)
<i>Critical effect(s)</i>	Nasal hyaline degeneration of olfactory epithelium; forestomach epithelium hyperplasia and ulcer; hemolytic anemia
<i>Hazard index target(s)</i>	Respiratory system; alimentary system (esophagous); hematologic system

II. Physical and Chemical Properties ((HSDB, 2005)except as noted)

<i>Description</i>	Colorless liquid
<i>Molecular formula</i>	$\text{C}_6\text{H}_{14}\text{O}_2$
<i>Molecular weight</i>	118.20 g/mol
<i>Density</i>	0.90 g/cm ³ @ 20 °C
<i>Boiling point</i>	171 °C
<i>Melting point</i>	-70 °C
<i>Vapor pressure</i>	0.76 mm Hg @ 20 °C
<i>Odor threshold in air</i>	0.10 ppm (geometric mean) (AIHA, 1989)
	Sweet, ester-like, musty
<i>Solubility</i>	Miscible in water and soluble in most organic solvents
<i>Conversion factor</i>	1 ppm = 4.84 mg/m ³ @ 25° C

III. Major Indoor Uses, Sources and Quantified Exposures

Due to their excellent solvency, chemical stability and water compatibility, ethylene glycol monobutyl ether (EGBE) and other glycol ethers are good solvents for many applications and often act as coupling agents to stabilize immiscible ingredients. Consumer products and building materials that may contain EGBE include liquid wax

and wax strippers, varnish removers and lacquers, surface cleaners, water-based paints, nail enamel remover, permanent hair colorants, caulking and sealants, and resilient floorings (Anderson, 1996; Fang *et al.*, 1999; Zhu *et al.*, 2001; IWMB, 2003; HSDB, 2005). Microorganisms or molds have also been identified as possible emission sources for EGBE (McJilton *et al.*, 1990).

Based on product use scenarios developed by U.S. EPA and an assumed “standard room,” 1-hr average EGBE concentrations of 2.8 to 62 mg/m³ were estimated for all-purpose spray cleaners and spray glass cleaners which contained anywhere from 0.5 to 4% EGBE by weight (Zhu *et al.*, 2001). Actual air monitoring data by Vincent *et al.* (1993) support the modeled exposure data, in that concentrations of <0.5 to 35 mg/m³ EGBE have been recorded following use of EGBE-containing surface cleaners, though product concentrations of EGBE were generally higher (0.9 to 21.2% by weight). In a California study investigating emissions from consumer cleaning products during regular household use, EGBE was present at levels of 0.8-10% by mass in 6 of 17 products tested (Nazaroff *et al.*, 2006). One-hour average concentrations of 0.3 to 2.3 mg/m³ were measured immediately after simulated typical use in a room-sized chamber.

Chamber emission studies of new building materials found that some samples of non-rubber and tire-derived, rubber-based resilient floorings emitted EGBE (IWMB, 2003). An air concentration of 13 µg/m³ EGBE was estimated based on 96-hour emission rates when modeled to standard State office and classroom dimensions. In another study, four of 19 new samples of PVC-flooring materials emitted EGBE, resulting in a calculated concentration as high as 90 µg/m³ four weeks following installation in a small room (Lundgren *et al.*, 1999). The median emission rate of EGBE decreased by 51% between week 4 and 26 after manufacture.

Several workplace and residential VOC emission studies have analyzed for EGBE. A geometric mean concentration of 7.7 µg/m³ (range: <1.9-131 µg/m³) EGBE was recorded for 12 northern California office buildings in an indoor air quality study (Daisey *et al.*, 1994). In another study, eight of 11 densely occupied U.S. administrative offices emitted measurable levels of EGBE (Shields *et al.*, 1996). The geometric mean concentration was 1.0 µg/m³ ± 3.2 (GSD) with a maximum of 32 µg/m³. EGBE levels up to 81 µg/m³ were found in a new home but had decreased to 4-11 µg/m³ at 35 weeks following construction (Brown, 2002). The emissions were thought to originate from water-based paints or adhesives.

IV. Effects of Human Exposure

Accidental exposures of humans to high levels of EGBE vapors originating from misuse of concentrated EGBE cleaning products resulted in immediate intense eye and respiratory irritation, marked dyspnea, nausea, and faintness (Raymond *et al.*, 1998). Long-term effects attributed to high acute exposures include recurrent eye and respiratory irritation, dry cough, headache, and dermal cherry angiomas. EGBE concentrations near

silkscreening equipment that resulted in complaints of odor and sensory irritation during use were found to range from 13 to 169 ppm (Kullman, 1987).

In sensitive mammalian species such as rats, mice, and hamsters, hemolytic anemia and increased erythrocyte osmotic fragility are primary toxic endpoints of EGBE exposure. However, simultaneous chamber exposures of rats and men to EGBE (113 ppm for 4 hrs) have shown humans to be insensitive to these toxic endpoints compared to rats (Carpenter *et al.*, 1956). *In vitro* studies also show considerably less risk of hemolysis in human erythrocytes compared to rat erythrocytes when blood is incubated with 2-butoxyacetic acid (Corley *et al.*, 1994; Udden, 2002). Physiologically-based pharmacokinetic (PBPK) modeling of human exposures to saturated atmospheres of EGBE showed that the maximum blood concentration of 2-butoxyacetic acid (2BAA), the metabolite primarily responsible for hemolysis, is below that needed to produce this effect (Johanson and Johnsson, 1991; Corley *et al.*, 1997). PBPK modeling simulations have also found that the maximum venous blood concentration of 2BAA in adult humans are similar to or below that of rats and mice (Corley *et al.*, 2005). The resistance of RBC's in healthy adults to the hemolytic effects of 2BAA *in vitro* extends to erythrocytes from elderly individuals, children and individuals with sickle cell disease or hereditary spherocytosis (Udden, 1994; Udden, 2002). Nevertheless, anecdotal reports of hemoglobinuria and anemia have been reported following exposure to very high concentrations of EGBE (Carpenter *et al.*, 1956; Raymond *et al.*, 1998).

In human volunteers, the elimination half-life of EGBE in blood is about 40 min and the elimination half-life of the primary metabolite 2BAA in urine is about 6 hr (Johanson *et al.*, 1986; Jones and Cocker, 2003). PBPK modeling of EGBE in workers continually exposed indicates that elimination from the most poorly perfused organs is rapid and that EGBE does not appear to accumulate in the body (Johanson, 1986). However, small amounts of free and conjugated 2BAA were found in urine of EGBE-exposed workers the following morning after a work shift, indicating slight accumulation of the metabolite in the body (Sakai *et al.*, 1994). EGBE exposure levels (breathing zone TWA) during a work week were mostly between 0.2 and 0.8 ppm, with urinary elimination of the metabolite almost complete over the weekend.

In whole-body chamber studies, volunteers were exposed to 98 (two men and one woman) or 195 ppm (two men and two women) for a total of 8 hrs (Carpenter *et al.*, 1956). Eye, nose and throat irritation, taste disturbances, and headache and nausea were reported. Exposure of two men to 113 ppm for 4 hrs produced similar effects. Erythrocyte osmotic fragility and urinalysis were normal in the subjects during and after exposure. In the other chamber study, seven healthy male adults exposed to 20 ppm (100 mg/m³) EGBE for 2 hours did not have any complaints or show any adverse effects from exposure (Johanson *et al.*, 1986). In a more recent chamber study, whole body 2-hr exposure of four volunteers to 49 ppm EGBE did not result in physiological changes in breathing rate, pulse rate, skin surface temperature or skin resistance (Jones *et al.*, 2003). The volunteers did not report sensory irritation or CNS effects during the whole body exposure (Jones, 2005). The odor was noted on entering the chamber and some

volunteers found it initially unpleasant. However perception of the smell diminished over time during exposure.

Haufroid *et al.* (1997) conducted a worker study on a cross-section of 31 male workers exposed to low levels of EGBE in a beverage packing plant. The average airborne concentration of EGBE was $0.59 \text{ ppm} \pm 0.27 \text{ (SD)}$ and there was good correlation between EGBE in air and post-shift urinary 2BAA concentrations. A slight but significant effect on erythroid parameters (hematocrit and mean corpuscular hemoglobin concentration) suggested membrane damage in exposed workers, but no significant effect was found on other erythroid parameters. U.S. EPA (1999) noted that both affected values were still within normal clinical ranges, further indicating that additional studies are needed to confirm if these changes represent early markers of EGBE toxicity in workers. In another occupational study, the hematological status of nine parquet floorers exposed to a mean 8-hr concentration of 24.6 mg/m^3 (5.1 ppm) EGBE (max: 350 mg/m^3 (72 ppm)) by personal air sampling was determined (Denkhaus *et al.*, 1986). Erythrocyte number showed a slight, but insignificant ($0.05 < P < 0.1$) decrease, but hemoglobin concentration was unaffected. Co-exposure to a number of other chemicals in the worker group also occurred.

While some studies note a good correlation between EGBE in air and urinary 2BAA concentrations, one study measured high levels of urinary 2BAA in office and car cleaners using EGBE even though air concentrations of EGBE were often lower than 0.5 ppm (Vincent *et al.*, 1993). This finding suggested that skin penetration of EGBE in unprotected workers could be the predominant source of exposure. Dermal exposure studies in human volunteers show EGBE solutions are well absorbed dermally and could represent a dominant route of exposure (Jakasa *et al.*, 2004; Kezic *et al.*, 2004). Based on urinary butoxyacetic acid levels in ‘whole body’ and ‘skin only’ EGBE chamber exposures, dermal absorption of EGBE vapors averaged 11% of the total body dose (Jones *et al.*, 2003). PBPK modeling estimations by Corley *et al.* (1997) under similar baseline conditions produced similar dermal absorption results (15% of total body dose) via vapor exposure. Wearing overalls during exposure increased dermal absorption probably by forming a warmer, more humid microclimate next to the skin that promoted absorption (Jones *et al.*, 2003).

IV. Effects of Animal Exposure

The principal toxic effect of sub-lethal exposure to EGBE in sensitive species is a reversible hemolytic anemia caused primarily by the metabolite 2BAA.

In experimental animals, sex and age-related differences were observed in the toxicokinetics of the metabolite 2BAA, following inhalation of EGBE. In 19-month-old mice, EGBE was rapidly cleared from the systemic circulation, exhibiting clearance profiles similar to young mice 6-7 weeks old (Dill *et al.*, 1998). However, old mice eliminated 2BAA from blood over 10 times slower than young mice after 1-day exposure. This delayed elimination of 2BAA in old mice was less obvious after 3 weeks

of exposure. In rats, a sex-related difference in 2BAA elimination was observed with rats, as females were about half as efficient in clearing 2BAA from the blood than males.

The primary route of EGBE metabolism in animals is via alcohol dehydrogenase to 2-butoxyacetaldehyde, which is then rapidly converted by aldehyde dehydrogenases to 2BAA (Ghanayem *et al.*, 1987b; Green *et al.*, 2002). These enzymes are present in many tissues including portal of entry tissues such as the epithelium of the nose and stomach (Agarwal, 2001). Apart from the hemolytic effect of 2BAA, the metabolite is also considered a chronic contact irritant that results in damage of the forestomach epithelium in mice (Green *et al.*, 2002; Poet *et al.*, 2003). A similar mechanism of action in rat and mouse nasal epithelium also likely occurs (Gift, 2005). The parent compound, EGBE, appears to have only a fraction of the cellular irritant capacity that its metabolite 2BAA has, and the first metabolite generated, 2-butoxyacetaldehyde, is likely too rapidly metabolized by aldehyde dehydrogenases to be a significant contributor to cellular irritation (Green *et al.*, 2002).

The NTP (2000) conducted a 14-wk whole-body EGBE inhalation exposure study in rats and mice. Exposure (6 hr/day, 5 days/wk) to 31, 62.5, 125, 250, and 500 ppm EGBE resulted in clinical findings of abnormal breathing, pallor, red urine stains, nasal and eye discharge, lethargy, and increased salivation and/or lacrimation primarily at the three highest concentrations in rats, and at the highest concentration in mice. The primary effect was a concentration-related hemolytic anemia in male rats and mice exposed to 125 ppm and above and, to a greater extent, in all exposed groups of female rats and mice. Exposure-related increases in the incidences of Kupffer cell pigmentation of the liver, forestomach inflammation and epithelial hyperplasia, bone marrow hyperplasia (rats only), splenic hematopoietic cell proliferation, and renal tubule pigmentation were observed in male and/or female rats and mice surviving to the end of the study. Most of these effects were secondary to red cell hemolysis and regenerative anemia, with female rats showing the greatest sensitivity – statistically significant increases in Kupffer cell pigmentation and bone marrow hyperplasia were apparent in female rats at concentrations as low as 62.5 ppm.

In a subsequent 2-year study, the NTP (2000) exposed rats and mice to 31.2 (rats only), 62.5, 125, and 250 (mice only) ppm EGBE for 6-hr/day, 5 days/wk. The principal toxic endpoints not linked to red blood cell hemolysis are presented in Table 1. In rats, the anemia was considered mild and persisted with no apparent progression or amelioration of severity from 3 months to final blood collection at 12 months. Anemia occurred at 3, 6, and 12 months in 62.5 ppm females and 125 ppm males and females. An anemia also occurred in 31.2 ppm females at 3 and 6 months, and there was evidence of an anemia in 62.5 ppm males at 12 months. In the 62.5 and 125 ppm EGBE exposure groups at terminal sacrifice (i.e., 2-years), incidences of Kupffer cell pigmentation were increased in male and females and incidences of splenic fibrosis were increased in males. Incidences of hyaline degeneration of the olfactory epithelium were increased in all exposed groups of males, and in females exposed to 62.5 or 125 ppm. The severity of this lesion was minimal and not affected by exposure.

In the mouse exposure study, hematological assessment was also made at 3, 6, and 12 months of exposure, with pathology assessment occurring at terminal sacrifice following 2-year exposure (NTP, 2000). Persistent, exposure-related anemia was present at 3, 6, and 12 months of exposure in 125 and 250 ppm male and female mice. There was also evidence of anemia in 62.5 ppm female mice at 6 months. Survival of males was reduced at 125 and 250 ppm. Increased incidences of forestomach ulcer and hyperplasia, Kupffer cell pigmentation, and nasal hyaline degeneration of olfactory and respiratory epithelium, occurred in all groups of exposed female mice. In male mice, there was an increased incidence of forestomach ulcer at 125 ppm, and an increased incidence of bone marrow hyperplasia, and Kupffer cell pigmentation at 125 and 250 ppm. All groups of exposed males showed increased incidence of forestomach hyperplasia. A mouse urologic infection syndrome was apparent in males, and appeared to be exacerbated by EGBE exposure at 125 and 250 ppm.

Table 1: Two-year EGBE inhalation study: Incidence of nasal hyaline degeneration of olfactory epithelium in rats and mice, and incidence of forestomach epithelial hyperplasia and ulcer in mice (NTP, 2000).

	Exposure Group (ppm)				
	0	31.2	62.5	125	250
Nasal olfactory epithelium lesions					
Male Rats	13/48	21/49*	23/49*	40/50*	-----
Female Rats	13/50	18/48	28/50*	40/49*	-----
Male Mice	4/50	-----	10/50	5/48	5/48
Female Mice	6/50	-----	14/50*	11/49*	12/50*
Forestomach Epithelial Hyperplasia					
Male Mice	1/50	-----	7/50 [†]	16/49 ^{††}	21/48 ^{††}
Female Mice	6/50	-----	27/50 ^{††}	42/49 ^{††}	44/50 ^{††}
Forestomach Ulcer					
Male Mice	1/50	-----	2/50	9/49 ^{††}	3/48
Female Mice	1/50	-----	7/50 [†]	13/49 ^{††}	22/50 ^{††}

* significantly different from control group at $P < 0.05$ by poly-k test.

[†] and ^{††} - significantly different from control group at $P \leq 0.05$ and $P \leq 0.01$, respectively, by Poly-3 test

Similar concentration-response results for anemia in rodents were observed in earlier studies. Dodd *et al.* (1983) observed a NOAEL and LOAEL of 20 and 86 ppm, respectively, for anemia following 9-day exposure (6 hr/day, 5 days/week) of male and female rats to EGBE. A subsequent 90-day EGBE exposure study (6 hr/day, 5 days/week) observed a NOAEL and LOAEL of 25 and 77 ppm, respectively, for anemia in male and female rats. The severity of RBC depression in the 90-day study was not increased compared to the 9-day study.

Carpenter *et al.* (1956) exposed rats, guinea pigs, mice, dogs, and monkeys to EGBE for 7 hr/day, 5 days/week for up to 90 exposures. In rats, groups of males and females were exposed to 54, 107, 203, 314, or 432 ppm EGBE for 4 weeks. Deaths occurred at 314 ppm and higher, and evidence of hemoglobinuria was evident at concentrations of 203 ppm and higher. A dose-dependent increase in increased osmotic fragility beginning at

54 ppm was observed. Groups of 10 male guinea pigs exposed to 54, 107, 203, 376, or 494 ppm EGBE for 4 weeks did not show evidence of red blood cell hemolysis at any concentration. Lung congestion and kidney damage was the only finding among the three animals that died at 376 ppm or higher. Groups of mice exposed to 112, 200 or 400 ppm EGBE for up to 90 exposures exhibited transient hemoglobinuria at the highest concentration and increased red blood cell fragility at all concentrations. No mortality occurred and no gross pathology of organs was observed 42 days after cessation of exposure.

In higher mammals, Carpenter *et al.* (1956) observed decreased hematocrit values and increased leucocyte count in dogs exposed to 100 or 200 ppm EGBE for up to 90 and 31 exposures, respectively. In addition to these findings, two dogs exposed repeatedly to 385 ppm also exhibited nasal and ocular infection, generalized weakness, apathy, anorexia, emesis and death by the 28th exposure. In two monkeys exposed to 100 ppm EGBE (90 exposures) and one rhesus monkey exposed to 210 ppm EGBE (30 exposures), increased red blood cell fragility was observed at both concentrations and emesis at the highest concentration. Pulmonary tuberculosis was found in the monkeys at autopsy, but no other noteworthy histopathological findings were observed.

EGBE is not listed as a developmental or reproductive toxicant under Proposition 65 (OEHHA, 2005). Unlike some structurally-similar glycol ethers listed under Proposition 65, EGBE exposure did not result in toxicity to male testes in 90-day rat inhalation studies by Dodd *et al.* (1983) or in 14-week and 2-year mouse and rat inhalation studies by the NTP (2000). In developmental toxicity investigations, Tyl *et al.* (1984) exposed pregnant rats and rabbits to 25, 50, 100, or 200 ppm EGBE for 6 hr/day on gestational days 6-15 for rats or days 6-18 for rabbits. Maternal toxicity in rats included decreased body weight gain, decreased food consumption, and evidence of anemia in the 100 and 200 ppm groups. Embryotoxicity was seen at the highest concentration and delayed skeletal ossification in offspring was observed at 100 and 200 ppm. In rabbits, maternal toxicity included deaths, spontaneous abortions and decreased body weight at 200 ppm, but hematological parameters were normal. Embryotoxicity, indicated by reduced gravid uterine weight and a concomitant reduction in total and viable implants was observed at the same concentration. In another developmental study, Nelson *et al.* (1984) exposed pregnant rats to 150 or 200 ppm EGBE 7 hr/day on days 7-15 of gestation. Maternal evidence of hematuria was observed only on the first day of exposure at both concentrations, and no fetotoxicity was seen in the offspring.

V. Derivation of Indoor 8-Hour Reference Exposure Level

OEHHA is currently re-evaluating the methods for REL development, primarily to ensure adequate protection of infants and children. Thus, RELs developed with the current methodology may be revisited in the future.

<i>Study</i>	NTP (2000)
<i>Study population</i>	F344/N rats (50 animals/group/gender)
<i>Exposure method</i>	Discontinuous whole-body inhalation exposure of 0, 31.2, 62.5, 125 ppm
<i>Critical effects</i>	Nasal hyaline degeneration of olfactory epithelium
<i>LOAEL</i>	31.2 ppm
<i>NOAEL</i>	Not observed
<i>BMC₀₅</i>	8.2 ppm (probit model)
<i>Exposure continuity</i>	6 hours per day, 5 days/week
<i>Exposure duration</i>	2 years
<i>Average experimental exposure</i>	6.2 ppm (8.2 ppm x 6/8 x 5/5)
<i>Human Equivalent Concentration</i>	6.2 ppm (based on pharmacokinetic analysis for an organic gas causing specific nasal olfactory lesions (Frederick <i>et al.</i> , 1998; Frederick <i>et al.</i> , 2001))
<i>LOAEL uncertainty factor</i>	1 (with use of a BMC ₀₅)
<i>Subchronic uncertainty factor</i>	1
<i>Interspecies uncertainty factor</i>	3 (for pharmacodynamic uncertainties)
<i>Intraspecies uncertainty factor</i>	30
<i>Cumulative uncertainty factor</i>	100
<i>Eight-hour reference exposure level</i>	0.06 ppm (0.3 mg/m ³ , 300 µg/m ³ , 60 ppb)

While human data is preferred for development of an 8-hr REL, the occupational data were inadequate for a REL derivation. The cumulative incidence of nasal tissue damage in rats with chronic exposure and the observation of slight accumulation of the toxic EGBE metabolite in workers with daily work-week exposure to EGBE supports a REL derivation based on long-term intermittent exposure. The human occupational data investigated only hematological endpoints and did not look for other organ and tissue changes. Consequently, the comprehensive chronic rodent exposure study by the NTP (2000) was used for REL development.

Sensitive endpoints of chronic EGBE exposure besides red blood cell hemolysis and the associated secondary effects were nasal hyaline degeneration of olfactory epithelium in male and female rats and female mice, and forestomach epithelial hyperplasia and ulcer in mice (Table 1). BMC₀₅s, NOAELs, and LOAELs for these endpoints are shown in Table 2. The BMC₀₅ represents the lower 95% confidence interval of the 5% response

rate and is considered to be similar to a NOAEL in estimating a concentration associated with a low level of risk.

U.S.EPA (1999) determined a BMC₀₅ of 27 ppm for decreased RBC count in female rats based on the 14-week study by the NTP (2000). Considering the *in vivo* and *in vitro* evidence of human insensitivity to the hemolytic effects of EGBE relative to rodent exposures, the greater importance of dose-rate rather than cumulative dose for RBC hemolysis, and that nasal olfactory tissue damage is similar to or greater in terms of sensitivity compared to RBC hemolysis and forestomach injury, a BMC₀₅ based on nasal olfactory tissue damage should also be protective for possible RBC hemolysis as well as esophageal tissue damage.

Chronic contact irritation to EGBE, and in particular the EGBE metabolites 2-butoxyacetic acid and 2-butoxyacetaldehyde, have been implicated in the damage to the forestomach in mice (Green *et al.*, 2002; Poet *et al.*, 2003). A similar mechanism of action in rat and mouse nasal olfactory epithelium also likely occurs (Gift, 2005). Interspecies differences for metabolism of EGBE by alcohol dehydrogenase to 2-butoxyacetic acid in the rodent forestomach is thought to play a role in the development of epithelial hyperplasia and ulcers. Although humans do not have an organ similar to the rodent forestomach, the human esophagus has histological similarities to this organ (IARC, 2005). However, the food storage function of the forestomach, a factor thought to lead to EGBE-related forestomach injury, does not have a corollary in the human esophagus (Boatman *et al.*, 2004). Nevertheless, the human esophagus is considered a potential target for EGBE toxicity, particularly since EGBE accumulates in the mouse esophagus and forestomach via inhalation and intravenous routes of exposure (Green *et al.*, 2002). The mouse glandular stomach was unaffected by EGBE exposure in the NTP study (Poet *et al.*, 2003). Similar to the human stomach, the mouse glandular stomach is secretory and probably protected from injury by a layer of mucus.

The lowest BMC₀₅ of 8.2 ppm, based on nasal olfactory epithelial damage in rats, was used for the REL derivation. The increased incidence of this age-related nasal lesion with increasing EGBE exposure was considered a mild adverse affect resulting from the irritant properties of EGBE. Given that both males and female rats exhibited a similar dose-response trend for this effect, all rats were combined for the BMC calculation. The BMC models for dichotomous data gave BMC₀₅ values primarily in the range of 4.6 to 12 ppm for the nasal lesion. The probit model provided the best visual and statistical fit to the data, particularly in the low dose region of the line where the BMC₀₅ resides. This model also supplied the lowest AIC (Akaike information criterion), another method recommended by U.S. EPA (USEPA, 2003) for choosing a BMC₀₅ in instances where acceptable model fits to the data were similar.

Table 2: BMC₀₅'s, NOAEL's and LOAEL's for EGBE in ppm for nasal and forestomach epithelial lesions in rats and mice following 2-year inhalation exposure (NTP, 2000).

Endpoint	BMC ₀₅ ^a	NOAEL	LOAEL
Nasal olfactory epithelium lesions[†]			
Male rats	8.0 (probit) ^b	NE ^c	31.2
Female rats	7.5 (probit)	31.2	62.5
Male and female rats combined	8.2 (probit)	-----	-----
Female mice	NA ^d	NE	62.5
Forestomach Epithelial Hyperplasia			
Male Mice	16.2 (Weibull)	NE	62.5
Female Mice	9.7 (log-probit)	NE	62.5
Forestomach Ulcer			
Female Mice	17.5 (quantal-linear)	NE	62.5

^a BMC_{05s} for the dichotomous data were calculated using U.S. EPA Benchmark Dose Software (USEPA, 2003)

^b BMC₀₅, in ppm, based on model (in parenthesis) with best visual and statistical fit

^c Not established; lowest EGBE concentration tested was the LOAEL for the endpoint

^d Not applicable; the data provided a poor dose-response curve for BMC determination

The average experimental exposure was adjusted for eight-hour exposures, five days/week. The standard HEC adjustment was not used for dosimetric interspecies extrapolation. Instead, species information based on pharmacokinetic modeling for toxicants that result in specific nasal olfactory tissue damage was applied for interspecies extrapolation of EGBE toxicity. The U.S. EPA HEC dosimetric adjustment for the extrathoracic region assumes uniform distribution within the entire nasal cavity and 100% uptake, and does not take into account specific target regions of the nasal cavity, in this case, the olfactory region. Dosimetry data for the nasal olfactory epithelium shows that the rat is more efficient in scrubbing organic vapors in this region of the nasal cavity than in humans (Frederick *et al.*, 1998; Frederick *et al.*, 2001). Consequently, rats receive a similar, or greater, tissue dose of inhaled organic vapors than humans in the olfactory epithelium. This interspecies difference in the deposition of inhaled vapors can be attributed to differences in airflow patterns and the distribution of epithelia between the two species.

Aldehyde dehydrogenase is the enzyme responsible for the formation of metabolite 2BAA, the primary chemical cellular irritant. Comparisons of aldehyde dehydrogenase activity in rat and human nasal tissue using a gas uptake technique indicates that the activities of the rat olfactory enzymes were about equivalent to those of humans, and Km values did not differ between species (Bogdanffy *et al.*, 1998).

Although specific nasal alcohol and aldehyde dehydrogenase enzyme activity using EGBE as a substrate is lacking, the combined dosimetric and metabolism information should be sufficient for any residual interspecies toxicokinetic differences and support a HEC adjustment = 1. In rats, the olfactory epithelium is particularly sensitive to organic acids (Frederick *et al.*, 1998). This is a major factor for olfactory tissue damage, even though the specific activity of aldehyde dehydrogenase is greater in the respiratory

epithelium (Bogdanffy *et al.*, 1998; Stanek and Morris, 1999). The relative nasal tissue sensitivity in humans to EGBE or other inhaled gases is unknown. Thus, a default $UF_{A-d} = 3.16$ was applied to account for nasal tissue sensitivity differences between species.

For the intraspecies adjustment, the lack of toxicokinetic and toxicodynamic information to assess the human variability of the nasal effects from inspired EGBE necessitates an intraspecies default $UF = 31.6$ ($10 (UF_{H-k}) \times 3.16 (UF_{H-d})$). Support for this UF includes human data for genetic polymorphisms and ethnic variation in the enzymes responsible for EGBE metabolism, primarily alcohol and aldehyde dehydrogenases (Agarwal, 2001). Age and gender-related differences in metabolism and elimination of EGBE have also been observed in animals (Dill *et al.*, 1998). Application of the rounded cumulative $UF = 100$ resulted in an 8-hour REL of 0.06 ppm (0.3 mg/m^3) for EGBE.

VII. Evidence for Differential Sensitivity of Children

No human inhalation studies were found that addressed differential sensitivity of children exposed to NMP relative to adult exposure. In experimental animals, no evidence was found for differential sensitivity in developmental studies, as both maternal toxicity and fetotoxicity occurred at similar exposure concentrations. Regarding the hemolytic action of EGBE, an animal oral gavage study found that adult (9-13 weeks) male rats were significantly more sensitive to the hemolytic effects of EGBE than young (4-5 weeks) male rats (Ghanayem *et al.*, 1987a). In humans, *in vitro* studies in erythrocytes from children and healthy adults showed no difference in their resistance to the hemolytic effects of 2-butoxyacetic acid (Udden, 1994; Udden, 2002).

VIII. Data Strengths and Limitations for Development of the REL

Significant strengths for the indoor REL include independent animal studies demonstrating similar toxic effects, a 2-year exposure study in rodents, PBPK model data, *in vivo* studies that support the relative insensitivity of humans to the hemolytic effects of EGBE, and *in vitro* studies for elderly and infants that show lack of increased sensitivity to the hemolytic effects of EGBE. Limitations include the lack of human toxicity data with chronic exposure, and lack of 2-generation developmental studies in animals.

IX. Executive Summary

Ethylene glycol mono-n-butyl ether (EGBE) is used in consumer products and building materials due to its excellent solvency ability. Consumer products and building materials that may contain EGBE include liquid wax and wax strippers, varnish removers and lacquers, surface cleaners, water-based paints, nail enamel remover, permanent hair colorants, caulking and sealants, and resilient floorings.

An Indoor Reference Exposure Level (IREL) is a “safe” air concentration of a chemical at or below which no adverse effects are anticipated for repeated daily 8-hour exposures. The 8-hour IREL for EGBE is based on the adverse health effect reported in the medical

and toxicological literature that occurs at the lowest air concentration of the chemical. It includes a margin of safety to protect the most sensitive individuals in the diverse general population, and to account for scientific uncertainties. Exposure to EGBE at concentrations above the IREL does not necessarily mean that health effects will occur because of the margin of safety. However, the likelihood of health effects increases as exposure concentrations increase above the IREL concentration.

The health effects that occur with EGBE exposure in animal experiments include inflammation and tissue damage in the nose and esophagus, and red blood cell loss. Accidental exposures of humans to high levels of EGBE vapors from misuse of concentrated EGBE cleaning products resulted in immediate intense eye and respiratory irritation, breathlessness, nausea, and faintness. Repeated high, short-term exposures to humans cause recurrent eye and lung irritation, dry cough, and headaches. The 8-hr REL is based on the highest tested concentration that did not result in the health effects found at yet higher concentrations in the rat study, or the No-Observed-Adverse-Effect-Level (NOAEL), with a margin of safety.

X. References

- Agarwal, D. P. (2001). Genetic polymorphisms of alcohol metabolizing enzymes. *Pathol Biol (Paris)* **49**, 703-709.
- AIHA (1989). Odor thresholds for chemicals with established occupational health standards. American Industrial Hygiene Association, Akron, OH. p. 14.
- Anderson, F. A. (1996). Final report on the safety assessment of butoxyethanol. *Journal of the American College of Toxicology* **15**, 462-526.
- Bogdanffy, M. S., Sarangapani, R., Kimbell, J. S., Frame, S. R., and Plowchalk, D. R. (1998). Analysis of vinyl acetate metabolism in rat and human nasal tissues by an in vitro gas uptake technique. *Toxicol Sci* **46**, 235-246.
- Brown, S. K. (2002). Volatile organic pollutants in new and established buildings in Melbourne, Australia. *Indoor Air* **12**, 55-63.
- Carpenter, C. P., Keck, G. A., Nair, J. H., 3rd, Pozzani, U. C., Smyth, H. F., Jr., and Weil, C. S. (1956). The toxicity of butyl cellosolve solvent. *AMA Arch Ind Health* **14**, 114-131.
- Corley, R. A., Bormett, G. A., and Ghanayem, B. I. (1994). Physiologically based pharmacokinetics of 2-butoxyethanol and its major metabolite, 2-butoxyacetic acid, in rats and humans. *Toxicol Appl Pharmacol* **129**, 61-79.
- Corley, R. A., Grant, D. M., Farris, E., Weitz, K. K., Soelberg, J. J., Thrall, K. D., and Poet, T. S. (2005). Determination of age and gender differences in biochemical processes affecting the disposition of 2-butoxyethanol and its metabolites in mice and rats to improve PBPK modeling. *Toxicol Lett* **156**, 127-161.
- Corley, R. A., Markham, D. A., Banks, C., Delorme, P., Masterman, A., and Houle, J. M. (1997). Physiologically based pharmacokinetics and the dermal absorption of 2-butoxyethanol vapor by humans. *Fundam Appl Toxicol* **39**, 120-130.
- Daisey, J. M., Hodgson, A. T., Fisk, W. J., Mendell, M. J., and Ten Brinke, J. (1994). Volatile organic compounds in twelve California office buildings: Classes, concentrations and sources. *Atmospheric Environment* **28**, 3557-3562.

- Denkhaus, W., von Steldern, D., Botzenhardt, U., and Konietzko, H. (1986). Lymphocyte subpopulations in solvent-exposed workers. *Int Arch Occup Environ Health* **57**, 109-115.
- Dill, J. A., Lee, K. M., Bates, D. J., Anderson, D. J., Johnson, R. E., Chou, B. J., Burka, L. T., and Roycroft, J. H. (1998). Toxicokinetics of inhaled 2-butoxyethanol and its major metabolite, 2-butoxyacetic acid, in F344 rats and B6C3F1 mice. *Toxicol Appl Pharmacol* **153**, 227-242.
- Dodd, D. E., Snellings, W. M., Maronpot, R. R., and Ballantyne, B. (1983). Ethylene glycol monobutyl ether: acute, 9-day, and 90-day vapor inhalation studies in Fischer 344 rats. *Toxicol Appl Pharmacol* **68**, 405-414.
- Fang, L., Clausen, G., and Fanger, P. O. (1999). Impact of temperature and humidity on chemical and sensory emissions from building materials. *Indoor Air* **9**, 193-201.
- Frederick, C. B., Bush, M. L., Lomax, L. G., Black, K. A., Finch, L., Kimbell, J. S., Morgan, K. T., Subramaniam, R. P., Morris, J. B., and Ultman, J. S. (1998). Application of a hybrid computational fluid dynamics and physiologically based inhalation model for interspecies dosimetry extrapolation of acidic vapors in the upper airways. *Toxicol Appl Pharmacol* **152**, 211-231.
- Frederick, C. B., Gentry, P. R., Bush, M. L., Lomax, L. G., Black, K. A., Finch, L., Kimbell, J. S., Morgan, K. T., Subramaniam, R. P., Morris, J. B., and Ultman, J. S. (2001). A hybrid computational fluid dynamics and physiologically based pharmacokinetic model for comparison of predicted tissue concentrations of acrylic acid and other vapors in the rat and human nasal cavities following inhalation exposure. *Inhal Toxicol* **13**, 359-376.
- Ghanayem, B. I., Blair, P. C., Thompson, M. B., Maronpot, R. R., and Matthews, H. B. (1987a). Effect of age on the toxicity and metabolism of ethylene glycol monobutyl ether (2-butoxyethanol) in rats. *Toxicol Appl Pharmacol* **91**, 222-234.
- Ghanayem, B. I., Burka, L. T., and Matthews, H. B. (1987b). Metabolic basis of ethylene glycol monobutyl ether (2-butoxyethanol) toxicity: role of alcohol and aldehyde dehydrogenases. *J Pharmacol Exp Ther* **242**, 222-231.
- Gift, J. S. (2005). U.S. EPA's IRIS assessment of 2-butoxyethanol: the relationship of noncancer to cancer effects. *Toxicol Lett* **156**, 163-178.
- Green, T., Toghill, A., Lee, R., Moore, R., and Foster, J. (2002). The development of forestomach tumours in the mouse following exposure to 2-butoxyethanol by inhalation: studies on the mode of action and relevance to humans. *Toxicology* **180**, 257-273.
- Haufroid, V., Thirion, F., Mertens, P., Buchet, J. P., and Lison, D. (1997). Biological monitoring of workers exposed to low levels of 2-butoxyethanol. *Int Arch Occup Environ Health* **70**, 232-236.
- HSDB (2005). Hazardous Substances Data Bank. Ethylene Glycol Mono-N-Butyl Ether (CASRN: 11-76-2). Chemical/Physical Properties. National Library of Medicine, Bethesda, MD. Available at: <http://toxnet.nlm.nih.gov>.
- IARC (2005). Summary report: Squamous-cell tumours of the forestomach. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Online at: <http://www-cie.iarc.fr/htdocs/iarcpubs/techpub39/summary1.html>.
- IWMB (2003). Integrated Waste Management Board. Building Material Emissions Study. Sacramento, CA. Available at: www.ciwmb.ca.gov/Publications.

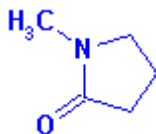
- Jakasa, I., Mohammadi, N., Kruse, J., and Kezic, S. (2004). Percutaneous absorption of neat and aqueous solutions of 2-butoxyethanol in volunteers. *Int Arch Occup Environ Health* **77**, 79-84.
- Johanson, G. (1986). Physiologically based pharmacokinetic modeling of inhaled 2-butoxyethanol in man. *Toxicol Lett* **34**, 23-31.
- Johanson, G., and Johnsson, S. (1991). Gas chromatographic determination of butoxyacetic acid in human blood after exposure to 2-butoxyethanol. *Arch Toxicol* **65**, 433-435.
- Johanson, G., Kronborg, H., Naslund, P. H., and Byfalt Nordqvist, M. (1986). Toxicokinetics of inhaled 2-butoxyethanol (ethylene glycol monobutyl ether) in man. *Scand J Work Environ Health* **12**, 594-602.
- Jones, K. (2005). Electronic communication.
- Jones, K., and Cocker, J. (2003). A human exposure study to investigate biological monitoring methods for 2-butoxyethanol. *Biomarkers* **8**, 360-370.
- Jones, K., Cocker, J., Dodd, L. J., and Fraser, I. (2003). Factors affecting the extent of dermal absorption of solvent vapours: a human volunteer study. *Ann Occup Hyg* **47**, 145-150.
- Kezic, S., Meuling, W. J., and Jakasa, I. (2004). Free and total urinary 2-butoxyacetic acid following dermal and inhalation exposure to 2-butoxyethanol in human volunteers. *Int Arch Occup Environ Health*.
- Kullman, G. J. (1987). NIOSH Health Hazard Evaluation Report No. HETA 87-273-1866, U.S. Department of Health and Human Services, Cincinnati, OH.
- Lundgren, B., Jonsson, B., and Ek-Olausson, B. (1999). Materials emission of chemicals-PVC flooring materials. *Indoor Air* **9**, 202-208.
- McJilton, C. E., Reynolds, S. J., Streifel, A. J., and Pearson, R. L. (1990). Bacteria and indoor odor problems - three case studies. *Am. Ind. Hyg. Assoc. J.* **51**, 545-549.
- Nazaroff, W. W., Coleman, B. K., Destailats, H., Hodgson, A. T., Liu, D.-L., Lunden, M. M., Singer, B. C., and Weschler, C. J. (2006). Indoor air chemistry: Cleaning agents, ozone, and toxic air contaminants. Final report: Contract no. 01-336. Prepared for the California Air Resources Board and the California Environmental Protection Agency, Sacramento CA. pp. i-xxiv, 72, 77, 88, 92, 97-98, 220, 223, 224-225.
- Nelson, B. K., Setzer, J. V., Brightwell, W. S., Mathinos, P. R., Kuczuk, M. H., Weaver, T. E., and Goad, P. T. (1984). Comparative inhalation teratogenicity of four glycol ether solvents and an amino derivative in rats. *Environ Health Perspect* **57**, 261-271.
- NTP (2000). Toxicology and Carcinogenesis Studies of 2-Butoxyethanol (CAS No. 111-76-2) in F344/N Rats and B6C3F1 Mice (Inhalation Studies). NTP TR 484. National Toxicology Program, Research Triangle Park, NC.
- OEHHA (2005). Proposition 65 - Governor's List. Chemicals Known to the State to Cause Cancer or Reproductive Toxicity. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. Online at: www.oehha.ca.gov/prop65/prop65_list/Newlist.html.
- Poet, T. S., Soelberg, J. J., Weitz, K. K., Mast, T. J., Miller, R. A., Thrall, B. D., and Corley, R. A. (2003). Mode of action and pharmacokinetic studies of 2-

- butoxyethanol in the mouse with an emphasis on forestomach dosimetry. *Toxicol Sci* **71**, 176-189.
- Raymond, L. W., Williford, L. S., and Burke, W. A. (1998). Eruptive cherry angiomas and irritant symptoms after one acute exposure to the glycol ether solvent 2-butoxyethanol. *J Occup Environ Med* **40**, 1059-1064.
- Sakai, T., Araki, T., Morita, Y., and Masuyama, Y. (1994). Gaschromatographic determination of butoxyacetic acid after hydrolysis of conjugated metabolites in urine from workers exposed to 2-butoxyethanol. *Int Arch Occup Environ Health* **66**, 249-254.
- Shields, H. C., Fleischer, D. M., and Weschler, C. J. (1996). Comparisons among VOCs measured in three types of U.S. commercial buildings with different occupant densities. *Indoor Air* **6**, 2-17.
- Stanek, J. J., and Morris, J. B. (1999). The effect of inhibition of aldehyde dehydrogenase on nasal uptake of inspired acetaldehyde. *Toxicol Sci* **49**, 225-231.
- Tyl, R. W., Millicovsky, G., Dodd, D. E., Pritts, I. M., France, K. A., and Fisher, L. C. (1984). Teratologic evaluation of ethylene glycol monobutyl ether in Fischer 344 rats and New Zealand white rabbits following inhalation exposure. *Environ Health Perspect* **57**, 47-68.
- Udden, M. M. (1994). Hemolysis and deformability of erythrocytes exposed to butoxyacetic acid, a metabolite of 2-butoxyethanol: II. Resistance in red blood cells from humans with potential susceptibility. *J Appl Toxicol* **14**, 97-102.
- Udden, M. M. (2002). In vitro sub-hemolytic effects of butoxyacetic acid on human and rat erythrocytes. *Toxicol Sci* **69**, 258-264.
- USEPA (1999). Toxicological Review of Ethylene Glycol Monobutyl Ether (EGBE) (CAS No. 111-76-2) In Support of Summary Information on the Integrated Risk Information System (IRIS). U.S. Environmental Protection Agency, Washington DC. Online at: <http://www.epa.gov/iris/subst/index.html>.
- USEPA (2003). Benchmark Dose Software, U.S. Environmental Protection Agency, National Center for Environmental Assessment. Online at: <http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm>.
- Vincent, R., Cicoletta, A., Subra, I., Rieger, B., Poirot, P., and Pierre, F. (1993). Occupational exposure to 2-butoxyethanol for workers using window cleaning agents. *Appl. Occup. Environ. Hyg.* **8**, 580-586.
- Zhu, J., Cao, X. L., and Beauchamp, R. (2001). Determination of 2-butoxyethanol emissions from selected consumer products and its application in assessment of inhalation exposure associated with cleaning tasks. *Environ Int* **26**, 589-597.

N-METHYL-2-PYRROLIDONE

(1-methyl-2-pyrrolidone; 1-methylpyrrolidone; N-methylpyrrolidone; N-methyl-2-pyrrolidinone; 1-methylpyrrolidinone)

CAS Registry Number: 872-50-4



I. Toxicity Summary

8-Hour Indoor Inhalation
reference exposure level
Critical effect(s)

2000 µg/m³ (600 ppb)

Reduced maternal and fetal body weight and
maternal weight gain in rats during
development.

Hazard index target(s)

General toxicity

II. Physical and Chemical Properties ((HSDB, 2005)except as noted)

Description	Colorless liquid
Molecular formula	C ₅ H ₉ NO
Molecular weight	99.13 g/mol
Density	1.027 g/cm ³ @ 25 °C
Boiling point	202 °C
Melting point	-25 °C
Vapor pressure	0.345 mm Hg @ 25 °C
Odor threshold in air	25-50 mg/m ³ for vapor (Akesson and Paulson, 1997). Mild amine or acetone-like odor
Solubility	Miscible in water, lower alcohols and ketones; moderately soluble in aliphatic hydrocarbons
Conversion factor	1 ppm = 4.12 mg/m ³ @ 20° C

III. Major Indoor Uses, Sources and Quantified Exposures

N-methyl-2-pyrrolidone (NMP) is a dipolar, hygroscopic solvent used for extraction in the petrochemical industry, as a reactive medium in polymeric and non-polymeric chemical reactions, as a remover of graffiti, as a paint stripper in the occupational setting, and for stripping and cleaning applications in the microelectronics fabrication industry (WHO, 2001). It is also used as a formulating (solvent) agent in pigments, dyes, and inks

and in various pesticides, as an intermediate in the pharmaceutical industry, as a penetration enhancer for topically applied drugs, and as a vehicle in the cosmetics industry. Indoor residential and office exposure to NMP would likely result from its use as a formulating agent in vinyl coating products, gloss emulsion paints, and floor finishes (Beaulieu and Schmerber, 1991). NMP use is increasing, primarily as a substitute for chlorinated hydrocarbon solvents or other hazardous high vapor pressure solvents, since it is perceived as a solvent with lower inherent toxicity (Beaulieu and Schmerber, 1991; WHO, 2001).

An emissions study of new building materials found that some samples of carpet and tire-derived, rubber-based resilient floorings emitted NMP (IWMB, 2003). Air concentrations based on 96-hour emission rates, when modeled to standard State office and classroom dimensions, ranged from 47 to 53 $\mu\text{g}/\text{m}^3$ from carpets, and 0.8 to 14 $\mu\text{g}/\text{m}^3$ from resilient floorings. NMP has been proposed as a solvent for use in the devulcanization process of used rubber tire crumb (Sharma, 2000). However, it is unclear if residual NMP from this process is responsible for the NMP emissions from carpets and tire-derived, rubber-based resilient floorings. In another study, three of 19 new samples of PVC-flooring materials not fixed to a support emitted NMP (Lundgren *et al.*, 1999). The median emission rate of NMP decreased 67% between week 4 and 26 after manufacture. The emission rate of NMP from waterborne acrylic floor varnish applied to flooring roughly tripled with increasing relative humidity from 30% to 70%, or increasing temperature from 18°C to 28°C (Fang *et al.*, 1999; Knudsen *et al.*, 1999).

Relatively few indoor exposure studies have analyzed for NMP. In two new California relocatable classrooms, the average NMP concentration measured over 8 weeks during school hours was 1.40 and 3.75 $\mu\text{g}/\text{m}^3$ (overall range: 0.66-7.37 $\mu\text{g}/\text{m}^3$) (Hodgson *et al.*, 2004). The emissions originated from vinyl-covered fiberboard wall panels. The NMP emission rate in the classrooms was 2-3 mg/h prior to occupancy, but had dropped below the lower limit of quantitation 8-weeks after first occupancy. In a Finnish population exposure study, indoor, outdoor and personal exposures were determined for NMP and other VOCs in a subgroup of 183 participants (Edwards *et al.*, 2001). Only 1-2% of samples collected showed measurable levels of NMP, with maximum levels of 90.6, 4.8 and 42.5 $\mu\text{g}/\text{m}^3$ observed for indoor, outdoor and personal exposure, respectively.

IV. Effects of Human Exposure

Occupational exposure to NMP vapor has resulted in eye irritation and headaches, and acute irritant dermatitis on contact of the liquid with skin (Beaulieu and Schmerber, 1991; Leira *et al.*, 1992). Skin contact with NMP liquid in volunteers has been shown to result in extensive percutaneous absorption and may contribute considerably to overall uptake of the solvent in the workplace (Akrill *et al.*, 2002). Significant dermal absorption with exposure to NMP predominantly in the aerosol form is anticipated, although no quantitative studies have been conducted to assess the contribution of dermal absorption vs. inhalation with exposure to NMP aerosol. However, aqueous dilution of NMP significantly decreases the dermal absorption of the solvent (Akeson *et al.*, 2004).

A number of pharmacokinetic studies have been conducted in humans by the inhalation route. NMP is readily absorbed by the respiratory route and is predominantly excreted as urinary NMP metabolites. Exposure of 6 male volunteers to 20 mg/m³ NMP for 8 hrs resulted in a peak NMP plasma concentration of 10 µmol/l (0.99µg/ml) and a plasma half-life 3.3 hrs (Carnerup *et al.*, 2006). In urine, 1.3% of the total amount excreted was unchanged NMP. The corresponding fractions of urinary NMP metabolites was 55-57% as 5-hydroxy-N-methyl-2-pyrrolidone (5-HNMP), 1.5-1.6% as N-methylsuccinimide (MSI), 39-40% as 2-hydroxy-N-methylsuccinimide (2-HMSI), and 1.4-1.5% as 2-methylpyrrolidone. The plasma half-lives of the metabolites that could be quantified was 7.1 hrs for 5-HNMP, 4.6 hrs for MSI, and 16 hrs for 2-HMSI. Similar pharmacokinetic results have been recorded in humans by other researchers (Akesson and Jonsson, 1997; Akesson and Jonsson, 2000). The volumes of distribution found for inhaled NMP and the metabolites 5-HNMP and 2-HMSI (28 to 41 L) suggests a distribution mainly to the water pool in the body (Jonsson and Akesson, 2003). The volume of distribution above 100 L for MSI suggests a distribution to a larger pool than just body water.

Workers exposed to a time-weighted average (TWA) of 0.09-0.69 ppm NMP for 12 hr/day showed insignificant accumulation in prior-to-shift and end-of-shift plasma and urine concentrations of NMP during a workweek (Xiaofei *et al.*, 2000). A pharmacokinetic model based on worker and volunteer exposures estimated that 8-hr exposures to a concentration as high as 12 ppm NMP will result in only a 3% increase in end-of-shift NMP concentrations in urine and plasma from Monday to Friday, indicating negligible accumulation of NMP during the workweek.

Carnerup *et al.* (2006) investigated differences in NMP absorption under conditions of low or high humidity. Six male volunteers were exposed for 8 hr on four different occasions to air levels of 0 and 20 mg/m³ NMP in dry (20% relative humidity) and humid air (80% relative humidity). There were no differences in the total cumulated excretion of NMP and its metabolites in urine, or in the levels of peak concentrations in either plasma or urine, after exposure in humid air as compared to dry air. However, there were large individual differences, especially with exposure in humid air. There was no formation of larger particles during the exposure in humid air, even though sodium chloride particles were generated (3000-6000 particles/cm³) in the chamber to act as condensation nuclei.

Eight-hour TWA personal breathing zone exposures to warm NMP and the accompanying physical perceptions were determined in approximately eight microelectronic plant workers during work hours (Beaulieu and Schmerber, 1991). In addition, sensory irritation was assessed by groups of 1 to 6 workers with brief area exposures to NMP in various plant locations. An 8-hr TWA concentration of 0.72-1.50 ppm (3.0-6.2 mg/m³) was perceived as having a mild, yet pungent odor, was uncomfortable after about 30 min, and resulted in chronic headaches in some workers with full shift exposures. Brief exposure and 8-hr TWA NMP exposures to <0.03 ppm (0.1 mg/m³) did not result in any effects. Exposure to 15-17 ppm (62-70 mg/m³) caused

immediate discomfort and minor eye irritation, while exposure to 49-83 ppm (202-342 mg/m³) was considered immediately unbearable.

In a chamber study, six volunteers did not report any subjective sensations of eye, nasal, or respiratory irritation with 8-hour exposures to 10, 25, or 50 mg/m³ NMP vapor (Akesson and Paulsson, 1997). Airway resistance changes measured by spirometry and nasal volume changes were not found, although two subjects noted an acetone-like odor at 50 mg/m³. It was speculated that the discrepancy in effects between the occupational and chamber studies was due to occupational processes that resulted in temperatures above the boiling point of NMP leading to brief high peak concentrations, or to warm, vaporized NMP condensing to an aerosol that is more irritating to the eyes and dermally absorbed (Akesson and Paulsson, 1997; Jonsson and Akesson, 2003).

Bader *et al.* (2006) conducted a field study to monitor the occupational exposure and possible irritative effects of 7 workers exposed to NMP. Average workplace concentrations of NMP (8-hr TWA) as well as some short-term peak exposures during the work shift were addressed by stationary and personal air monitoring. The worker with the highest exposure (15.5 mg/m³ TWA, 18.0 mg/m³ short-term peak exposure for 102 min, 85 mg/m³ maximum exposure for 5 min) reported irritative effects including lacrimation, headache, sore throat, and stomach pain. The worker with the second highest exposure (6.6 mg/m³ TWA, 18.7 mg/m³ short-term peak exposure for 19 min) reported a disturbance of the upper respiratory tract upon inhalation of NMP containing aerosols both during and after the work shift. The NMP 'aerosol' was not further characterized by the study. The 8-hr TWA NMP exposures for the other workers that did not experience sensory irritation ranged from 0.9 to 3.4 mg/m³. The researchers noted that some of the workers also had dermal exposure to NMP that likely increased the internal dose higher than would have been expected on the basis of ambient monitoring alone. The biomonitoring results suggested that NMP and NMP metabolites were back below detectable levels in pre-shift urine samples of the 7 volunteers.

In a case report, intrauterine growth retardation followed by stillbirth at 31 weeks occurred in a female worker who sustained inhalation and dermal exposure to NMP throughout the first trimester of pregnancy (Solomon *et al.*, 1996). Autopsy found no fetal anomalies and maternal risk factors were minimal. However, high exposure during an NMP spill at the 16th week of gestation appeared to have resulted in maternal toxicity following exposure, including dermal chemical stains, malaise, headache, nausea, and vomiting. The level of exposure was unknown. While stillbirth in this period of pregnancy was considered unusual, there was no additional data to support exposure to NMP was a causative factor

IV. Effects of Animal Exposure

No peer-reviewed toxicokinetic studies in experimental animals by the inhalation route were located in the literature.

In a toxicokinetic study via oral exposure (125 or 500 mg/kg by gavage), NMP and the metabolites 5-HNMP, N-methylsuccinimide, 2-HMSI and 2-pyrrolidone were identified in plasma and urine of rats (Carnerup *et al.*, 2005). These same metabolites have been identified in human toxicokinetic studies by Akesson and Jonsson (1997) and Carnerup *et al.* (2006). In urine, 48% of the administered dose was recovered as 5-HNMP, 2-5% as 2-HMSI, and 1-4% as unchanged NMP. The total recovery from urine of the rats was 53-59%, which represented 99-100% of the amount eliminated by this route within 24 hrs of administration. Repeated oral administration over three consecutive days found no obvious accumulation of NMP or NMP metabolites in urine.

In rats, intravenously administered [^{14}C]NMP is extensively metabolized and rapidly excreted in urine (Payan *et al.*, 2002). The volume of distribution was 70% of body weight, which corresponds to the total aqueous volume of the animal. At doses of 10 mg/kg or less, unchanged NMP in plasma declined linearly with time until 3 hr after administration indicating intensive glomerular reabsorption. It then declined exponentially with a half-life of 0.8 hr. Between 4 and 6% of the administered doses were excreted in the urine as unchanged NMP. 5-HNMP was the main urinary metabolite and accounted for 42 to 45% of administered doses, which is similar to the value obtained in human volunteers after oral and inhalation exposure (Akesson and Jonsson, 1997; Akesson and Jonsson, 2000). In other intravenous toxicokinetic studies, the urinary excretion of radiolabeled NMP and NMP metabolites accounted for about 70% of the dose within 12 hrs and 80% within 24 hrs (Wells and Digenis, 1988). About 70-75% of the dose was eliminated in urine as the metabolite 5-HNMP (Wells and Digenis, 1988; Wells *et al.*, 1992).

In a 4-week whole-body exposure study, rats exposed to 100, 500, or 1000 mg/m³ aerosolized NMP (>95% of the droplets below 10 μm in diameter) for 6 hr/day, 5 days/week showed signs of lethargy and irregular respiration in all treatment groups after about 3-4 hr of exposure (Lee *et al.*, 1987). Rats in the two lowest exposure groups recovered from these effects within 30-45 minutes post-exposure. Most 1000 mg/m³ rats did not recover from the effects between exposures, resulting in excessive mortality and termination of the test at this concentration after 10 days. Other observed effects occurred only at 1000 mg/m³, including hematological changes (increased relative and absolute numbers of neutrophils and decreased relative number of lymphocytes), focal pneumonia, bone marrow hypoplasia, and atrophy of lymphoid tissue in the spleen and thymus. In contrast, an industry study observed no treatment-related mortality in rats exposed to 1800 mg/m³ (435 ppm) NMP vapor (generated by a heating element) for 6 hr/day, 5 days/week for 6 weeks (BASF, 1983). Urine was intensely yellow and was attributed to a yellow metabolite. Light nasal secretion started on the eighth day of exposure, but no respiratory or other pathological organ changes were observed at the end of 6-week exposure.

To investigate the toxicity of NMP under different test atmospheres, a series of industry studies explored the interaction of NMP aerosol fraction, relative humidity (RH), and area of exposure in female rats exposed to 1000 mg/m³ (243 ppm) for 6 hr/day, 5 days/week for 2 weeks (GAF, 1990; WHO, 2001). Head-only exposure to coarse NMP

particles (MMAD 4.4-4.5 μm) at 70% RH resulted only in nasal irritation while whole body exposure under the same conditions resulted in high mortality, changes in body weight and absolute organ weights, and spleen and bone marrow lesions. Cages, chamber walls and the fur of the animals were wet from NMP condensation. However, whole body exposure to fine particles (MMAD $<3\ \mu\text{m}$) at 70% RH resulted in nasal irritation symptoms, but no deaths. NMP droplets were observed on cages and chamber walls, but only minor amounts of NMP could be detected on the fur of the rats after exposure. Finally, whole body exposure to fine or coarse NMP particles at low humidity (10-15% RH) resulted in only minor respiratory changes and no mortality.

In a chronic whole-body inhalation study, groups of male and female rats were exposed primarily to NMP vapor (with a trace amount of NMP aerosol) at concentrations of 0, 40 or 400 mg/m^3 (0, 10 and 100 ppm) for 6 hr/day, 5 days/week for two years (Lee *et al.*, 1987; OEHHA, 2005). General observations included greater incidence of stained wet perineia and dark yellow urine in females of both treatment groups and 400 mg/m^3 males. In addition, male rats in the high exposure group had greater urine volume and 6% lower body weight (statistical significance not reported). No meaningful histopathological differences in kidneys or other organs were observed between control and exposure groups.

NMP is listed under Proposition 65 as a chemical known to cause developmental toxicity (OEHHA, 2005). Principal findings included a rabbit gavage teratology study, which observed resorptions and malformations in offspring at 540 mg/kg , and a rat multigeneration feeding study, which observed reductions in the male fertility index and the female fecundity index at 50 mg/kg or more. In a more recent rat gavage developmental toxicity study, NMP caused dose-dependent adverse effects on the embryo/fetal development, including embryoletality, teratogenicity, and growth retardation at concentrations of 250-500 mg/kg (Saillenfait *et al.*, 2002). No evidence of developmental toxicity was observed at 125 mg/kg . The findings of developmental and reproductive effects by non-inhalation routes of exposure resulted in the initiation of inhalation studies investigating similar endpoints.

Pregnant rats exposed to NMP aerosol at atmospheric concentrations of 100 or 360 mg/m^3 for 6 hr/day on days 6 through 15 of gestation exhibited sporadic lethargy and irregular respiration in several rats at both exposure levels during the first three days of exposure (Lee *et al.*, 1987). No other signs of maternal toxicity were observed. No differences in outcome of pregnancy, fetal development or fetal malformations were observed between control and treated groups. However, Hass *et al.* (1995) exposed pregnant rats to 0 and 165 ppm (680 mg/m^3) NMP vapor 6 hr/day during pre- and post-implantation phases of gestation (days 4 through 20), resulting in increased pre-implantation loss, lower fetal body weights, and delayed ossification, but without inducing maternal toxicity.

In the most comprehensively reported developmental study, pregnant rats were exposed to 0, 30, 60, or 120 ppm (0, 124, 247, and 494 mg/m^3) NMP vapor 6 hr/day during the post-implantation phase of gestational days (GD) 6 through 20 (Saillenfait *et al.*, 2003).

Average maternal food consumption during GD 6-21 was reduced at the highest exposure and maternal body weight gain was reduced during GD 6-13 at the two highest exposures. A slight reduction in absolute maternal body weight occurred at the highest exposure, but did not reach statistical significance ($p < 0.05$). Teratogenicity and embryo/fetal viability changes were not observed, although fetal weight was reduced at 120 ppm.

Benchmark concentration (BMC) estimates of the maternal/fetal body weight endpoints from Saillenfait *et al.* (2003) were derived when satisfactory concentration-dependent changes were observed (Table 1). For exposure-related changes in absolute body weights, the 95% lower confidence interval of a 5% reduction in the endpoint (i.e., the BMC₀₅) was calculated using the benchmark dose modeling software supplied by U.S. EPA (USEPA, 2003). The BMC₀₅ is considered to be equivalent to a NOAEL in estimating a low level of risk. For maternal weight gain change, a one standard deviation (SD) from the mean of the control group was roughly equivalent to a statistically significant ($p < 0.05$) reduction in weight gain. The 95% lower confidence interval at this point was also considered equivalent to a NOAEL in estimating a low level of risk. In Table 1, the greater dispersion in maternal body weights and lower number of animals/group resulted in a greater disparity between the maximum likelihood estimate (MLE = 5% response rate or 1 SD from the mean, depending on endpoint) and the BMC₀₅ for maternal body weight endpoints relative to the fetal body weights.

Table 1: BMC₀₅'s, MLE's, NOAEL's and LOAEL's for principal body weight and body weight gain reduction endpoints from the developmental study by Saillenfait *et al.*, (2003).

Maternal/Fetal Endpoint	BMC ₀₅ [†] (ppm)	MLE [†] (ppm)	NOAEL (ppm)	LOAEL (ppm)
Absolute maternal body weight on GD 21	59	120	120	NE ^{††}
Maternal weight gain during GD 6-13	41	94	30	60
Fetal body weight - males	86	117	60	120
Fetal body weight – females	56	84	60	120

[†] BMC₀₅ and MLE derived with the polynomial model for a continuous data set

^{††} Not estimated. A LOAEL could not be attained at the highest exposure concentration

Solomon *et al.* (1995) exposed rats to NMP vapor in a two-generation reproduction study with a developmental toxicity component. Male and female rats in the P₀ generation inhaled 0, 10, 51, or 116 ppm (0, 41, 210, or 478 mg/m³) NMP for 6 hr/day, 7 days/week from day 34 of age to the end of the mating period for the males (100 exposure days) and till weaning for the females (about 143 exposure days, but interrupted from day 20 of gestation to day 4 postpartum). On day 70 postpartum, F1 rats from exposed litters were mated with nonexposed adults to produce an F2 generation. The only sign of toxicity during exposure occurred in 116 ppm rats and consisted of a subjective finding of decreased responsiveness to sound. No differences in indices of reproductive performance (i.e., fertility, mating and gestation indices) were noted between NMP-exposed and control rats. Mean and relative weights of testes and ovaries in P₀ and F1 generations were unaffected by exposure. However, fetal weights of F1 offspring exposed to NMP during gestation up until day 21 postpartum were decreased 4-11%.

This effect was not clearly dose related and reached statistical significance for the 10 and 116 ppm groups, but not the 51 ppm group. In the developmental phase, rats of both sexes inhaled 0 or 116 ppm NMP as outlined above, but euthanization of the females occurred on Day 21 of gestation followed by fetal examination. No increase in fetal variations or malformations were observed compared to controls, and no changes in fetal/embryo viability, other than decreased fetal body weight, were observed compared to controls.

In a postnatal development and behavior study, offspring of pregnant rats exposed to 150 ppm (618 mg/m³) NMP vapor 6 hr/day during gestational days 7 through 20 resulted in reduced fetal body weight and about a half-day delay in some physical development milestones (Hass *et al.*, 1994). No maternal toxicity was evident; though the urine was colored bright yellow. Significantly lower pup body weights were still apparent up to 5 weeks of age. In subsequent tests in male offspring, motor function, activity level, and performance in learning tasks with a low grade of complexity were similar to controls, but higher cognitive functions related to solving difficult tasks (reversal procedure in Morris water maze, Skinner boxes) was impaired in the NMP-exposed rats.

VI. Derivation of the Indoor Air 8-Hour Reference Exposure Level

OEHHA is currently re-evaluating the methods for REL development, primarily to ensure adequate protection of infants and children. Thus, RELs developed with the current methodology may be revisited in the future.

<i>Study</i>	Saillenfait et al. (2003)
<i>Study population</i>	SD female rats (25-26 animals/group)
<i>Exposure method</i>	Discontinuous whole-body inhalation exposure of 0, 30, 60, 120 ppm during gestational days 6-20
<i>Critical effects</i>	Reduced fetal body weight
<i>LOAEL</i>	120 ppm
<i>NOAEL</i>	60 ppm
<i>BMC₀₅</i>	56 ppm
<i>Exposure continuity</i>	6 hr/day, 7 days/week during gestation
<i>Exposure duration</i>	15 days
<i>Average experimental exposure</i>	56 ppm (for developmental toxicity)
<i>Human equivalent concentration</i>	56 ppm, for gas with systemic effects, based on RGDR = 1.0 using default assumption that $\lambda(a) = \lambda(h)$
<i>LOAEL uncertainty factor</i>	1
<i>Subchronic uncertainty factor</i>	1 (see below)
<i>Interspecies uncertainty factor</i>	3
<i>Intraspecies uncertainty factor</i>	30
<i>Cumulative uncertainty factor</i>	100
<i>Indoor Air Reference exposure level</i>	0.6 ppm (2 mg/m ³ , 2000 µg/m ³ , 600 ppb)

Critical factors in the toxicity of NMP involves an accurate description of the test atmosphere generated in controlled exposure studies and a description of the atmospheric conditions present in indoor environments. Air temperature, and in particular the relative humidity (RH), defines the proportion of NMP that will exist as a vapor and as an aerosol. Human and animal evidence suggests that aerosolized NMP (i.e., coarse particles 3-4 µm or larger) is more potent than NMP vapor in producing discomfort, headache, sensory irritation and respiratory inflammation. However, the animal evidence indicates that NMP vapor may be more potent than it's aerosol phase in producing body weight reductions, particularly during gestational exposure. The 8-hr REL for NMP is based on toxicological studies for the vapor phase, the dominant form of NMP expected in most indoor environments.

The maximum vapor concentration for NMP at room temperature is 1318 mg/m³ (320 ppm) in dry air (0% RH), 412 mg/m³ (100 ppm) at a normal humidity (60% RH), and 0 mg/m³ in wet air of (100% RH) (GAF, 1990). Consequently, typical indoor environmental conditions of about 50-60% RH at temperatures of 20-25°C will result in NMP primarily in the vapor phase. This assumes the vapor concentration of NMP does not become saturated by rising above 100 ppm.

In their developmental study, Saillenfait *et al.* (2003) determined that 120-140 ppm NMP was the highest reliable vapor concentration technically possible under exposure conditions of 21°C and 50% RH. Higher concentrations would have resulted in increased formation of NMP aerosol and condensation of NMP onto animal fur and surfaces inside the chambers. Analysis of NMP air concentrations up to 120 ppm (at 23°C and 40-60% RH) found no detectable increase in NMP particle formation above 0.75 µm during generation of test atmospheres using a heating element to vaporize liquid NMP. The implication was that the NMP atmosphere generated was predominantly in the vapor phase. In addition, the study by Carnerup *et al.* (2006) could not generate an NMP aerosol at concentrations of 20 mg/m³ (5 ppm) and 80% RH even with sodium chloride particles present in the atmosphere to act as condensation nuclei. Such high NMP concentrations are unlikely, given that the maximum recorded NMP concentration from building materials emission studies and indoor exposure studies have not exceeded 90 µg/m³ (Edwards *et al.*, 2001).

In animals, sensitive endpoints of toxicity to NMP vapor exposure are limited to reductions in body weight and food consumption without apparent organ or tissue damage. The BMC₀₅ of 56 ppm, for reduced body weight in female rat offspring, was used for the 8-hr REL derivation. Other similar BMC₀₅'s were derived for reduced maternal absolute body weight (59 ppm) and male offspring body weight (86 ppm). A lower BMC₀₅ of 41 ppm, with a corresponding NOAEL of 30 ppm, was determined for reduced maternal weight gain. However, the reduced maternal weight gain of the LOAEL group exposed to 60 ppm NMP appeared to be transient at best, occurring only during GD 6-13. Maternal weight gain in this group was also low during the pre-exposure period GD 0-6 (30 g vs. 35 g in the control group), suggesting NMP exposure may have had little or no effect during GD 6-13. In other developmental studies, reductions in fetal weight were observed at higher NMP concentrations without causing maternal weight deficits (Hass *et al.*, 1994; Hass *et al.*, 1995). Thus, a REL derivation based on fetal body weight reduction was considered more appropriate, and should also be protective for reductions in maternal body weight and weight gain.

The BMC₀₅ of 56 ppm was not adjusted for average experimental exposure. Adjusting the studies' exposure (6 hr/day, 7 days/week during GD 6-20) to an average experimental exposure of 8 hr/day, 5 days/week would increase the exposure estimate only to 59 ppm. However, developmental endpoints are frequently manifested in a small window of time during gestation, which would indicate that a time duration adjustment is not warranted (OEHHA, 1999). In support of the average experimental exposure remaining at 56 ppm, both human and animal studies observed essentially no detectable urinary accumulation of NMP or metabolites with repeated exposure. For the human equivalent concentration (HEC), an RGDR = 1 was applied based on the assumption that the ratio of the animal blood:air partition coefficient is equal to the human blood:air partition coefficient, and based on other measured pharmacokinetic similarities of NMP and metabolites in humans and rats.

A subchronic UF = 1 was applied to the REL derivation. Although not a chronic study, the reduced fetal body weight endpoint is a function of exposure only during gestation, especially in the case of a non-accumulating compound such as NMP. Therefore, an UF to account for differences between subchronic and chronic exposure were not required. The chronic inhalation study by Lee *et al.* (1987) supports a subchronic UF = 1 for exposure in adult animals as well, in that only a marginal reduction in body weight (6% in males) was observed at 100 ppm and was the only apparent endpoint found besides increased urine volume. The statistical significance of the decreased body weight was not presented in the chronic study. However, no effects were observed at the lowest exposure concentration of 10 ppm.

For potential pharmacodynamic differences not accounted for by the HEC, an interspecies UF = 3.16 was applied. An intraspecies default UF = 30 ($UF_{H-k} = 10$; $UF_{H-d} = 3.16$) was used for protection of children. The intraspecies default UF = 30 applies for chemicals that have systemic effects and no information is available for the susceptibility of the developing child. Equivocal evidence supporting the intraspecies UF includes the 2-generation animal study by Solomon *et al.* (1995), in which exposure to 10 ppm NMP resulted in reduced body weight of F₁ rat offspring. However, no reduction in body weights of offspring was found at the mid-level concentration of 51 ppm, and no dose-response effect was observed. All groups of NMP vapor-exposed F₁ rats had body weights similar to those of the control group one-week post-exposure (i.e., following weaning). A return of body weights to control levels soon after cessation of NMP exposure would seem to suggest that the effect was real.

The worker study by Beaulieu and Schmerber (1991) indicates an occupational NOAEL for NMP of about 0.02 ppm (0.08 mg/m³) for physical perception of discomfort, sensory irritation and headache. The occupational study by Bader *et al.* (2006) suggests a 8-hr TWA NOAEL of 3.4 mg/m³ (0.8 ppm), and a LOAEL of 6.6 mg/m³ (1.6 ppm). However, the environmental conditions during the occupational exposures preclude them for use in an 8-hr REL derivation. The presence of high humidity and hot NMP (71-240°C) during the occupational processes in the Beaulieu and Schmerber study suggests that an NMP aerosol or mist had been formed and resulted in the symptoms of discomfort and headache at concentrations as low as about 0.7 ppm. These environmental conditions are unlikely to occur in schools and workplaces, apart from industrial settings, where the predominant phase of airborne NMP would be as a vapor. The occupational study by Bader *et al.* (2006) characterized NMP exposure at the LOAEL as an aerosol, although particle size was not described. For comparison, a considerably higher vapor phase NMP concentration of 50 ppm did not result in subjective or objective effects in an acute human chamber exposure study by Akesson and Paulsson (1997).

Additional information is lacking that restricts the usefulness of the occupational studies for an 8-hr REL derivation. NMP concentrations in the occupational study by Beaulieu and Schmerber were identified as 8-hr TWA personal breathing zone exposures, but it was clear from the work conditions that brief, high concentrations of NMP vapor and/or aerosol were generated. The high short-term concentrations the workers were exposed to was not described. For both occupational studies, the 8-hr LOAEL and NOAEL appears

to be based on only a few individuals, no information was given on the occupational work history of the workers, and the duration of symptoms following removal from exposure was not described.

Indoor environments that result in hot, humid conditions represents a possible limitation for the NMP vapor REL. Such environments with a RH very near 100% may result in airborne NMP primarily in the aerosol phase. NMP aerosol is likely more potent than NMP vapor in producing certain toxicological effects such as discomfort, sensory irritation, and headache. It is not entirely clear from the human and animal evidence whether repeated exposure to NMP aerosols represent acute recurrent effects or chronic effects. Nevertheless, given the limitations described above for the occupational studies, a comparative 8-hr REL for exposure to NMP aerosol can be derived. Beaulieu and Schmerber (1991) identified a NOAEL of 0.02 ppm (0.08 mg/m³) and a LOAEL of 0.72 ppm (3.0 mg/m³). An uncertainty factor of 10 applied to the NOAEL to account for variability in individual response results in an 8-hr REL of 0.008 mg/m³, or 8 µg/m³, for NMP in the aerosol phase.

VII. Evidence for Differential Sensitivity of Children

No human inhalation studies were found that addressed differential sensitivity of infants or children exposed to NMP relative to adult exposure. In animal exposure studies, maternal exposure to 150-165 ppm NMP vapor during gestation has resulted in increased pre-implantation loss, prolonged reductions in fetal body weights, delayed ossification, and impaired higher cognitive functions in rat offspring, all without inducing maternal toxicity (Hass *et al.*, 1994; Hass *et al.*, 1995). In a 2-generation study, reduced fetal weight was observed in F₁ offspring from the 116 ppm and 10 ppm exposure groups, but not from the mid-dose group of 51 ppm (Solomon *et al.*, 1995). No maternal weight reductions were observed at any NMP exposure. However, another study noted exposure concentrations of 120 ppm NMP vapor resulted in both maternal and fetal weight reductions (Saillenfait *et al.*, 2003).

Developmental and reproduction toxicity studies in experimental animals by non-inhalation routes of exposure have observed teratogenic effects in offspring, leading to the listing of NMP on the Proposition 65 list (OEHHA, 2005). However, the inhalation studies have not been entirely consistent with the non-inhalation studies. Gavage studies in rabbits and rats found malformations in offspring; inhalation studies in rats did not find this endpoint, although growth retardation was observed. A multi-generation NMP feeding study in rats found that the lowest dose tested resulted in reductions in the male fertility index and female fecundity index, but no apparent fetotoxicity; these reproduction endpoints, including ovary and testis weight changes, were not found at any concentration tested in a rat 2-generation inhalation study. Differences in species, strain, total daily intake, and route of exposure may all be factors for the lack of malformations in offspring with maternal inhalation exposure to NMP. However, evidence by Hass *et al.* (1994) indicates that inhalation exposure may result in prolonged and even permanent changes in offspring (i.e., neurobehavioural and growth retardation).

VIII. Data Strengths and Limitations for Development of the REL

Significant strengths for the 8-hr REL include (1) chronic and subchronic animal studies with histopathological analysis; and (2) reproduction/developmental and 2-generation studies in experimental animals

Major areas of uncertainty are (1) in humans, the lack of a clear association between vapor and aerosol forms of NMP and their respective critical endpoints of toxicity; (2) lack of characterization of NMP phase under typical environmental exposure conditions; (3) lack of an animal NOAEL for aerosol-phase NMP; and (4) lack of a dose-response for neurodevelopmental endpoints in animal developmental studies.

IX. Executive Summary

N-Methyl pyrrolidone (NMP) is used as a solvent primarily for stripping and cleaning applications. Solvents that contain NMP may have a mild acetone-like odor. NMP is also found in solvent-based adhesives used in building materials such as flooring materials and coverings.

A Indoor Reference Exposure Level (IREL) is a “safe” air concentration of a chemical at or below which no adverse effects are anticipated for repeated daily 8-hour exposures. The 8-hour IREL for NMP is based on the adverse health effect reported in the medical and toxicological literature that occurs at the lowest air concentration of the chemical. It includes a margin of safety to protect the most sensitive individuals in the diverse general population, and to account for scientific uncertainties. Exposure to NMP at concentrations above the IREL does not necessarily mean that health effects will occur because of the margin of safety. However, the likelihood of health effects increases as the exposure concentrations increase above the IREL concentration.

The symptoms of toxicity that occur in animal studies include loss of appetite and weight loss. While it is not well known what daily air concentrations will result in adverse effects in humans, short-term NMP exposure has resulted in headaches, stomach pain, and eye irritation and may be related to the loss of appetite and weight that is observed in rats. The 8-hr REL is based on the highest tested concentration that did not result in the adverse effects in rats found at yet higher concentrations, and is known as the No-Observed-Adverse-Effect-Level (NOAEL), with a margin of safety.

X. References

- Akesson, B., Carnerup, M. A., and Jonsson, B. A. (2004). Evaluation of exposure biomarkers from percutaneous absorption of N-methyl-2-pyrrolidone. *Scand J Work Environ Health* **30**, 306-312.
- Akesson, B., and Jonsson, B. A. (1997). Major metabolic pathway for N-methyl-2-pyrrolidone in humans. *Drug Metab Dispos* **25**, 267-269.

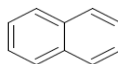
- Akesson, B., and Jonsson, B. A. (2000). Biological monitoring of N-methyl-2-pyrrolidone using 5-hydroxy-N-methyl-2-pyrrolidone in plasma and urine as the biomarker. *Scand J Work Environ Health* **26**, 213-218.
- Akesson, B., and Paulsson, K. (1997). Experimental exposure of male volunteers to N-methyl-2-pyrrolidone (NMP): acute effects and pharmacokinetics of NMP in plasma and urine. *Occup Environ Med* **54**, 236-240.
- Akrill, P., Cocker, J., and Dixon, S. (2002). Dermal exposure to aqueous solutions of N-methyl pyrrolidone. *Toxicol Lett* **134**, 265-269.
- Bader, M., Rosenberger, W., Rebe, T., Keener, S. A., Brock, T. H., Hemmerling, H. J., and Wrbitzky, R. (2006). Ambient monitoring and biomonitoring of workers exposed to N-methyl-2-pyrrolidone in an industrial facility. *Int Arch Occup Environ Health* **79**, 357-364.
- BASF (1983). Supplement No. 1 to the Report on Orientation Testing of Subacute Inhalation Toxicity of N-Methylpyrrolidone for Sprague-Dawley Rats. BASF Corp., Dept. of Toxicology, Germany. U.S. EPA New Doc I.D. 40-90107151. pp. 1-2, 4-7, 13, 16-17, 28-31.
- Beaulieu, H. J., and Schmerber, K. R. (1991). M-pyrol (NMP) use in the microelectronics industry. *Appl Occup Environ Hyg* **6**, 874-880.
- Carnerup, M. A., Saillenfait, A. M., and Jonsson, B. A. (2005). Concentrations of N-methyl-2-pyrrolidone (NMP) and its metabolites in plasma and urine following oral administration of NMP to rats. *Food Chem Toxicol* **43**, 1441-1447.
- Carnerup, M. A., Spanne, M., and Jonsson, B. A. (2006). Levels of N-methyl-2-pyrrolidone (NMP) and its metabolites in plasma and urine from volunteers after experimental exposure to NMP in dry and humid air. *Toxicol Lett* **162**, 139-145.
- Edwards, R. D., Jurvelin, J., Saarela, K., and Jantunen, M. (2001). VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki, Finland. *Atmospheric Environment* **35**, 4531-4543.
- Fang, L., Clausen, G., and Fanger, P. O. (1999). Impact of temperature and humidity on chemical and sensory emissions from building materials. *Indoor Air* **9**, 193-201.
- GAF (1990). Comments of GAF Chemicals Corporation, BASF Corporation and ARCO Chemical Corporation on the Proposed Test Rule for N-Methylpyrrolidone with Appendices and Attachments. U.S. EPA, Docket No. OPTS-42114, FRL 3712-9, May 29, 1990. pp. 10-16, 42, 44-47, 67-68.
- Hass, U., Jakobsen, B. M., and Lund, S. P. (1995). Developmental toxicity of inhaled N-methylpyrrolidone in the rat. *Pharmacol Toxicol* **76**, 406-409.
- Hass, U., Lund, S. P., and Elsner, J. (1994). Effects of prenatal exposure to N-methylpyrrolidone on postnatal development and behavior in rats. *Neurotoxicol Teratol* **16**, 241-249.
- Hodgson, A. T., Shendell, D. G., Fisk, W. J., and Apte, M. G. (2004). Comparison of predicted and derived measures of volatile organic compounds inside four new relocatable classrooms. *Indoor Air* **14 Suppl 8**, 135-144.
- HSDB (2005). Hazardous Substances Data Bank. 1-Methyl-2-pyrrolidinone: Chemical/Physical Properties. National Library of Medicine, Bethesda, MD. Available at: <http://toxnet.nlm.nih.gov>.

- IWMB (2003). Integrated Waste Management Board. Building Material Emissions Study. Sacramento, CA. Available at: www.ciwmb.ca.gov/Publications. pp. 1-57, Tables 53a-b, 59c, 16a-c, 23d-e.
- Jonsson, B. A., and Akesson, B. (2003). Human experimental exposure to N-methyl-2-pyrrolidone (NMP): toxicokinetics of NMP, 5-hydroxy- N-methyl-2-pyrrolidone, N-methylsuccinimide and 2-hydroxy- N-methylsuccinimide (2-HMSI), and biological monitoring using 2-HMSI as a biomarker. *Int Arch Occup Environ Health* **76**, 267-274.
- Knudsen, H. N., Kjaer, U. D., Nielsen, P. A., and Wolkoff, P. (1999). Sensory and chemical characterization of VOC emissions from building products: impact of concentration and air velocity. *Atmospheric Environment* **33**, 1217-1230.
- Lee, K. P., Chromey, N. C., Culik, R., Barnes, J. R., and Schneider, P. W. (1987). Toxicity of N-methyl-2-pyrrolidone (NMP): teratogenic, subchronic, and two-year inhalation studies. *Fundam Appl Toxicol* **9**, 222-235.
- Leira, H. L., Tiltner, A., Svendsen, K., and Vetlesen, L. (1992). Irritant cutaneous reactions to N-methyl-2-pyrrolidone (NMP). *Contact Dermatitis* **27**, 148-150.
- Lundgren, B., Jonsson, B., and Ek-Olausson, B. (1999). Materials emission of chemicals-PVC flooring materials. *Indoor Air* **9**, 202-208.
- OEHHA (1999). Air Toxics Hot Spots Program Risk Assessment Guidelines, Part I: The Determination of Acute Reference Exposure Levels for Airborne Toxicants. Section 1.6: Exposure Duration and Patterns, pp. 13-16. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment.
- OEHHA (2005). Chemicals Known to the State to Cause Cancer or Reproductive Toxicity. Dated December 2, 2005. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Online at: http://www.oehha.ca.gov/prop65/prop65_list/Newlist.html.
- Payan, J. P., Beydon, D., Fabry, J. P., Boudry, I., Cossec, B., and Ferrari, E. (2002). Toxicokinetics and metabolism of N-[14C]methylpyrrolidone in male Sprague-Dawley rats. A saturable NMP elimination process. *Drug Metab Dispos* **30**, 1418-1424.
- Saillenfait, A. M., Gallissot, F., Langonne, I., and Sabate, J. P. (2002). Developmental toxicity of N-methyl-2-pyrrolidone administered orally to rats. *Food Chem Toxicol* **40**, 1705-1712.
- Saillenfait, A. M., Gallissot, F., and Morel, G. (2003). Developmental toxicity of N-methyl-2-pyrrolidone in rats following inhalation exposure. *Food Chem Toxicol* **41**, 583-588.
- Sharma, K. R. (2000). Reclamation of rubber crumb from Army's discarded tires. Prepared for presentation at ANTEC 2000, Plastics Recycling, 40, May 7-11, Orlando, FL.
- Solomon, G. M., Morse, E. P., Garbo, M. J., and Milton, D. K. (1996). Stillbirth after occupational exposure to N-methyl-2-pyrrolidone. A case report and review of the literature. *J Occup Environ Med* **38**, 705-713.
- Solomon, H. M., Burgess, B. A., Kennedy, G. L., Jr., and Staples, R. E. (1995). 1-Methyl-2-pyrrolidone (NMP): reproductive and developmental toxicity study by inhalation in the rat. *Drug Chem Toxicol* **18**, 271-293.

- USEPA (2003). Benchmark Dose Software, National Center for Environmental Assessment. Online at:
<http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=20167>.
- Wells, D. A., and Digenis, G. A. (1988). Disposition and metabolism of double-labeled [3H and 14C] N-methyl-2-pyrrolidinone in the rat. *Drug Metab Dispos* **16**, 243-249.
- Wells, D. A., Hawi, A. A., and Digenis, G. A. (1992). Isolation and identification of the major urinary metabolite of N-methylpyrrolidinone in the rat. *Drug Metab Dispos* **20**, 124-126.
- WHO (2001). Concise International Chemical Assessment Document No. 35: N-Methyl-2-pyrrolidone. International Programme on Chemical Safety, World Health Organization, Geneva.
- Xiaofei, E., Wada, Y., Nozaki, J. I., Miyauchi, H., Tanaka, S., Seki, Y., and Koizumi, A. (2000). A linear pharmacokinetic model predicts usefulness of N-methyl-2-pyrrolidone (NMP) in plasma and urine as a biomarker for biological monitoring for NMP exposure. *J. Occup. Health* **42**, 321-327.

NAPHTHALENE

(naphthene, NCI-C5290, albocarbon, dezodorator, moth balls, moth flakes, tar camphor, white tar, naphthalin, naphthaline)
CAS Registry Number: 91-20-3



I. Toxicity Summary

8-Hour Indoor inhalation reference exposure level	13 µg/m³ (2.5 ppb)
Critical Exposure Duration	Repeated 8-hour exposures, 5 days/week)
Critical effect(s)	Respiratory effects (nasal inflammation, olfactory epithelial metaplasia, respiratory epithelial hyperplasia) in mice and rats
Hazard index target(s)	Respiratory system, blood systems

II. Physical and Chemical Properties (HSDB, 2006); except as noted)

Description	White crystalline powder; odor of mothballs
Molecular formula	C ₁₀ H ₈
Molecular Weight	128.6 g/mol
Density	4.42 g/cm ³ @ 20°C
Boiling point	218°C
Melting point	80.5°C
Vapor pressure	0.078 torr @ 25°C (Sonnenfeld et al., 1983); 0.10 torr @ 27°C (CRC, 1994)
Odor Threshold	200 µg/m ³ (AIHA, 1989)
Conversion factor	5.26 µg/m ³ per ppb at 25°C

III. Major Indoor Uses and Sources

Major sources of naphthalene indoors include building materials, such as carpet, plywood, cushions and vinyl flooring. Adhesives, and caulk can also emit naphthalene. Consumer products (e.g. household cleansers, furniture and floor-care products) can emit naphthalene (CARB, 2005). Environmental tobacco smoke (OEHHA, 2005) and wood smoke (HSDB, 2006) are also sources. The use of naphthalene in mothballs is being phased out.

Naphthalene is a natural constituent of coal tar (approximately 11%) (HSBD, 2006). It is present in gasoline and diesel fuels. It has also been used in the manufacture of phthalic anhydride, phthalic and anthranilic acids, naphthols, naphthylamines, 1-naphthyl-n-methylcarbamate insecticide, beta-naphthol, naphthalene sulfonates, synthetic resins, celluloid, lampblack, smokeless powder, anthraquinone, indigo, perylene, and hydronaphthalenes (NTP, 1992; HSDB, 2006). The statewide emissions from facilities reporting under the Air Toxics Hot Spots Act in California, based on the most recent available inventory for the year 2003, were estimated to be 76,290 pounds of naphthalene (CARB, 2006).

III. Regulatory Status

Naphthalene is already identified as a Toxic Air Contaminant as a result of its listing as a U.S. Hazardous Air Pollutant. For assessment of non-cancer effects, a Chronic Reference Exposure Level was adopted in 2000. Naphthalene was listed as a chemical known to the State of California to cause cancer on April 19, 2002, under Proposition 65. It was classified as Group 2B (possibly carcinogenic to humans) by the International Agency for Research on Cancer in 2002. OEHHA developed a cancer potency factor for naphthalene under the Hot Spots Program in 2005.

IV. Major Uses or Sources

V. Effects of Human Exposure

Nine persons (eight adults and one child) were exposed to naphthalene vapors from several hundred mothballs in their homes. Nausea, vomiting, abdominal pain, and anemia were reported (Linick, 1983). Testing at one home following the incident indicated an airborne naphthalene concentration of 20 ppb (105 $\mu\text{g}/\text{m}^3$). Symptoms abated after removal of the mothballs.

Workers occupationally exposed to naphthalene vapors or dust for up to five years were studied for adverse ocular effects (Ghetti and Mariani, 1956). Multiple pinpoint opacities developed in 8 of 21 workers. Vision did not appear to be impaired. Cataracts and retinal hemorrhage were observed in a 44-year-old man occupationally exposed to powdered naphthalene, and a coworker developed chorioretinitis (van der Hoeve, 1906). Wolf (1978) reported that a majority of 15 persons involved in naphthalene manufacture developed rhinopharyngolaryngitis.

Ingestion of naphthalene or p-dichlorobenzene mothballs is a frequent cause of accidental poisoning of children (Siegel and Wason, 1986). Infants exposed to naphthalene vapors from clothes or blankets have become ill or have died (U.S. EPA, 1990). Deaths have been reported following ingestion of naphthalene mothballs. A 17-year old male ingested mothballs, developed gastrointestinal bleeding, hematuria, and coma, and died after five

days (Gupta et al., 1979). A 30-year old female ingested 30 mothballs and died after five days (Kurz, 1987). A pregnant mother inhaled naphthalene from mothballs. Elevated levels of naphthalene were reported, along with hemolytic anemia and methemoglobinemia in both the mother and the infant (Molloy et al., 2004).

Acute hemolytic anemia was reported among 21 infants exposed to naphthalene vapors from nearby mothball-treated materials (Valaes et al., 1963). Increased serum bilirubin, methemoglobin, Heinz bodies, and fragmented red blood cells were observed. Kernicterus was noted in eight of the children, and two of the children died. Ten of these children had a genetic deficiency in glucose-6-phosphate dehydrogenase. A 12-year old male ingested 4 g of naphthalene and 20 hours later developed hematuria, anemia, restlessness, and liver enlargement (Manchanda and Sood, 1960). The patient recovered after 8 days. A 69-year old female developed aplastic anemia two months after several weeks of exposure to naphthalene and p-dichlorobenzene (Harden and Baetjer, 1978).

Coke oven workers were found to have higher levels of plasma 1,2-naphthoquinone-albumin adducts, a marker of naphthalene exposure (Dai et al., 2004). Urinary 1- and 2-naphthol also correlate with human naphthalene exposure (Preuss et al., 2004; Rappaport et al., 2004). Coke oven workers had 1,2-naphthoquinone adducts that tended to increase with age, which was suggested to result from declining P450 metabolism associated with aging (Waidyanatha et al., 2004).

VI. Effects of Animal Exposure

Male and female B6C3F1 mice were exposed to naphthalene (>99% pure) vapor for 6 hours per day, 5 days per week over 104 weeks (NTP, 1992). Concentrations used were 0 (150 mice), 10 (150 mice), or 30 ppm (300 mice) naphthalene (Table 1). Lesions were observed in the noses of exposed mice, including increased incidences of chronic nasal inflammation, olfactory epithelial metaplasia, and nasal respiratory epithelial hyperplasia.

Table 1. Incidence of respiratory tract lesions in mice (male and female combined) chronically exposed to naphthalene vapors (NTP, 1992)

	0 ppm	10 ppm	30 ppm
Nasal inflammation	3/139	34/134	108/270
Olfactory epithelial metaplasia	0/139	131/134	269/270
Nasal respiratory epithelial hyperplasia	0/139	131/134	269/270
Nasal respiratory epithelial degeneration	0/139	131/134	269/270

In a similar study, male and female F344/N rats were exposed to naphthalene (>99% pure) vapor for 6 hours per day, 5 days per week over 105 weeks (NTP, 2000). Concentrations used were 0, 10, 30 and 60 ppm naphthalene (Table 2). Lesions were observed in the nose-exposed rats, including increased incidences of olfactory epithelial inflammation, olfactory epithelial atrophy, and respiratory epithelial degeneration.

Table 2. Incidence of respiratory tract lesions in rats (male and female combined) chronically exposed to naphthalene vapors (NTP, 2000)

	0 ppm	10 ppm	30 ppm	60 ppm
Olfactory epithelial inflammation	0/98	96/98	95/97	93/98
Olfactory epithelial atrophy	3/98	98/98	97/97	94/98
Nasal respiratory epithelial hyperplasia	3/98	39/98	51/97	52/98
Nasal respiratory epithelial degeneration	8/98	53/98	53/97	47/98

CD-1 mice were administered 5.3, 53, or 133 mg/kg/day naphthalene by gavage over 90 days (Shopp et al., 1984). The only effect noted was inhibition of aryl hydrocarbon hydroxylase activity. No increase in mortality or changes in body weight were noted. Reduced spleen weights were noted in females exposed to the highest dose. No changes were noted in serum enzyme levels or electrolytes. The researchers did not conduct a histopathological examination.

B6C3F1 mice were administered 200 mg naphthalene/kg/day by gavage for 5 days per week over 13 weeks. No adverse effects were observed (U.S. EPA, 1990). Developmental effects of naphthalene ingestion in Sprague-Dawley CD rats were studied by Navarro and associates (1991). The lowest dose tested (50 mg/kg/day by gavage) was associated with signs of CNS depression for the first 3 days. No effect was observed on fetal growth, survival, and morphological development. However, a trend toward decreased fetal weight and increased malformations at 450 mg/kg/day compared with control animals was observed. An analysis of variance did not find a significant overall effect of dose on these parameters. The 450 mg/kg was described as a NOAEL for fetal development in the study.

Harris and associates (1979) intraperitoneally administered 395 mg/kg/day naphthalene to Sprague-Dawley rats over days 1 through 15 of gestation. Fetuses had a 50% increase in incidence in delayed cranial ossification and heart development. New Zealand white rabbits were given 0, 40, 200, or 400 mg/kg/day by gavage over days 6 through 18 of gestation (U.S. EPA, 1986a). A dose-dependent increase in maternal grooming, vocalization, aggression, diarrhea, dyspnea, and ocular and nasal discharge were noted at

all doses. No statistically significant increase in malformations or developmental abnormalities was observed.

Sprague-Dawley rats were administered 0, 100, 300, or 1000 mg/kg/day of naphthalene via dermal application (U.S. EPA, 1986b). No effects were reported at 100 or 300 mg/kg/day. At the high dose a slight decrease in testes weight was noted.

Induction of glutathione synthesis pathways is protective against nasal and pulmonary naphthalene toxicity (Phimister et al., 2004). Specifically, gamma-glutamylcysteine synthetase is induced following repeated naphthalene exposures (West et al., 2003; 2004).

VII. Derivation of Chronic Reference Exposure Level (REL)

Study	NTP (1992, 2000)
Study population	B6C3F1 mice (75 or 150/group/sex) and F344/N rats (50/group/sex)
Exposure method	Discontinuous whole-body inhalation exposures to 0, 10, 30, or 60 ppm naphthalene vapor
Critical effects	Nasal inflammation, olfactory epithelial atrophy, and nasal respiratory epithelial degeneration
LOAEL	10 ppm (>95% incidence of adverse nasal effects)
NOAEL	Not observed
Exposure continuity	6 hours/day for 5 days/week
8-Hour time-weighted exposure	7.5 ppm *(10 ppm x 6 hr/8 hr) for LOAEL group
Exposure duration	104 weeks
LOAEL uncertainty factor	10
Interspecies uncertainty factor	10
Intraspecies uncertainty factor	30
Cumulative uncertainty factor	3,000
Indoor reference exposure level (repeated 8-hour exposures, 5 days/week)	0.0025 ppm (2.5 ppb, 13 $\mu\text{g}/\text{m}^3$)

The NTP studies were chosen for the REL derivation since they are the best available animal inhalation bioassays involving repeated multiple-hour exposures, and because no adequate epidemiological studies of long-term human exposure were available. The studies were judged to be of adequate study design. The lack of nasal effects among control animals and the nearly total effect among animals exposed at 2 different concentrations strongly indicates a causal relationship between naphthalene exposure and nasal effects. The high incidence of effects at the lowest dose precludes using a Benchmark Dose Approach. The effects seen are consistent with those reported among exposed workers, who developed rhinopharyngolaryngitis or laryngeal carcinoma (Wolf,

1978). The hematological effects observed in humans have not been reported in laboratory animals, which raises the possibility that humans may be significantly more sensitive to naphthalene.

The most important limitation of the study is that the lowest concentration tested caused adverse effects in most (>96%) of the animals tested. Thus the study amply demonstrates the risk of lifetime exposures to 10 ppm, but is uninformative regarding the concentration-response relationship at lower concentrations. Only a general assumption can be drawn on the magnitude of uncertainty factor needed to predict a concentration at which adverse effects would most likely not be observed. Lacking specific guidance or relevant research for this situation, the default 10-fold factor was applied. According to U.S. EPA (2000), because of its low water solubility and low reactivity, naphthalene-related effects on the nasal epithelium are expected to result following absorption of naphthalene and its metabolism to reactive oxygenated metabolites, not from direct contact.

This is supported by data on naphthalene metabolism indicating that toxic effects on the respiratory tract are due to a naphthalene metabolite that may be formed either in the liver or in the respiratory tract. Necrosis of bronchial epithelial (Clara) cells in mice and necrosis of olfactory epithelium in mice, rats, and hamsters occur following intraperitoneal injection of naphthalene. The nasal effects from inhalation exposure to naphthalene were considered to be extra-respiratory effects of a category 3 gas (U.S. EPA, 1994). The assumption is made that nasal responses in mice to inhaled naphthalene are relevant to humans; however, it is uncertain that the RfC for naphthalene based on nasal effects will be protective for hemolytic anemia and cataracts, the better known effects from naphthalene exposure in humans.

Clara cell toxicity seen in mice is correlated with high levels of CYP2F2 and resultant higher levels of naphthalene-1, 2-epoxide formation in mouse lung (Baldwin et al., 2005). Rats have 4 to 8-fold overall lower lung expression of CYP2F than mice, and levels are 30 to 40 fold in some lung regions.

Expression of CYP2F was not detected in rhesus macaque lung. Highest levels of rodent CYP2F were noted in the nasal ethmoturbinates, with mouse expression being twice that of rats. Rhesus CYP2F was detected in nasal ethmoturbinates but not in other tissues tested. Nasal ethmoturbinates CYP2F levels were 10-fold lower in rhesus macaques than in rats (Baldwin et al., 2004). It is possible that humans might be less susceptible to nasal effects from naphthalene exposure than rodents, because primates tend to be a better model for humans. However, several issues remain unresolved: (1) it is unclear how similar human CYP2F pattern are to those of rhesus macaques, (2) the relative balance of toxification and detoxification pathways in humans (particularly sensitive human subgroups) is unknown, (3) humans may be more sensitive to other naphthalene effects that are not apparent in rodents studies. Buckpitt and colleagues (2002) made the point that caution is advised in extrapolating from these findings pending further research.

Thus while concern may be raised that the default 10-fold factor to estimate a no effect level from a LOAEL could be inadequate if the underlying dose-response relationship is not steep, the potential error may be offset by the use of the 30 fold intraspecies factor and the fact that the overall uncertainty factor for this REL is the 3,000 maximum that OEHHA previously recommended for an overall uncertainty factor (OEHHA, 2000). The observation that tolerance to some effects of naphthalene exposure develop as a result of induction of detoxification enzymes (West et al., 2002) suggests effects from single exposures might occur at concentration comparable to those causing chronic effects. Thus an indoor REL for a single exposure might reasonably be set at the same concentration as an indoor REL for repeated exposures.

VIII. Differential Impacts on Children

Cytochrome P-450 enzyme levels are known to be different in children than in adults (OEHHA, 2001). It is not specifically known if infants and children metabolize and detoxify naphthalene differently than adults in the nasal cavity and liver. However, it is clear that there is the potential for a wide range of intraspecies variability in the pharmacokinetics for this compound, thus justifying an intraspecies uncertainty factor of 30.

The trend toward decreased fetal weight and increased malformations at 450 mg/kg/day compared with control animals observed by Navarro and associates (1991). The 8-hour REL should be protective against these effects.

It must be noted that OEHHA is currently re-evaluating the methods for REL development, primarily to ensure adequate protection of infants and children. Thus, RELs developed with the current methodology may be revisited in the future.

IX. Data Strengths and Limitations for Development of the REL

The strengths of the REL for naphthalene include the large number of animals in the key studies on which the REL is based and the good study design. The limitations include the very high incidence of lesions at the lowest level tested in the key study, the absence of a NOAEL in the key study, the absence of studies in primates by the inhalation route, and the paucity of human data.

X. Executive Summary

Naphthalene is a common chemical in building materials and consumer products. Examples of building materials known to emit naphthalene include carpet, plywood, cushions and vinyl flooring. Household cleansers, furniture and floor-care products are examples of consumer products that may contain naphthalene. Environmental tobacco smoke and wood smoke also contain naphthalene.

An Indoor Reference Exposure Level (IREL) is a “safe” air concentration of a chemical at or below which no adverse effects are anticipated for repeated daily 8-hour exposures.

The 8-hour IREL for naphthalene is based on the adverse health effect reported in the medical and toxicological literature that occurs at the lowest air concentration of the chemical. It includes a margin of safety to protect the most sensitive individuals in the diverse general population, and to account for scientific uncertainties. Exposure to naphthalene at concentrations above the IREL does not necessarily mean that health effects will occur because of the margin of safety. However, the likelihood of health effects increases as the exposure concentration increases above the IREL concentration.

The health effects that occur with naphthalene exposure in animal experiments include nasal inflammation and damage to nasal tissues. Nausea, vomiting, blood disorders, effects on the liver have been described in humans following naphthalene exposure. Deaths have occurred with high exposures. The 8-hr REL is based on the highest concentration that did not result in these adverse effects in rats that occur at yet higher concentrations, and is known as the No-Observed-Adverse-Effect-Level (NOAEL), with a margin of safety.

XI. Reference List

- AIHA (1989) Odor thresholds for Chemicals with Established Occupation Health Standards. Akron, OH, American Industrial Hygiene Association
- ATSDR. 1990. Agency for Toxic Substances and Disease Registry. Toxicological Profile for Naphthalene and 2-Methylnaphthalene (Draft). Atlanta, GA: U.S. Public Health Service, U.S. Department of Health and Human Services.
- Baldwin RM, Shultz MA, Buckpitt AR. 2005. Bioactivation of the Pulmonary Toxicants Naphthalene and 1-Nitronaphthalene by Rat Cytochrome P4502F4. *J Pharmacol Exp Ther.* 312(2):857-65.
- Buckpitt A, Boland B, Isbell M, Morin D, Shultz M, Baldwin R, Chan K, Karlsson A, Lin C, Taff A, West J, Fanucchi M, Van Winkle L, Plopper C. 2002. Naphthalene-induced respiratory tract toxicity: metabolic mechanisms of toxicity. *Drug Metab Rev.* 34(4):791-820.
- CARB. 2005 Report to the California Legislature. Indoor Air Pollution in California.
- CARB. 2006. Air toxics emissions data collected in the Air Toxics Hot Spots Program CEIDARS Database.
- CRC. 1994. CRC Handbook of Chemistry and Physics, 75th edition. Lide DR, ed. Boca Raton, FL: CRC Press Inc. p. 6-109.
- Dai YF, Leng SG, Pan ZF, Rappaport SM, Zheng YX. 2004. [Preliminary study on naphthalene-metabolites-albumin adduct as an exposure biomarker for coke oven workers.] *Zhonghua Yu Fang Yi Xue Za Zhi.* 38(6):392-395. [Article in Chinese]

- Ghetti G, and Mariani L. 1956. [Eyes changes due to naphthalene]. *Med. Lav.* 47:533-538. [reviewed in ATSDR, 1995].
- Gupta R, Singhal PC, Muthusethupathy MA, Malik AK, Chugh KS. 1979. Cerebral oedema and renal failure following naphthalene poisoning. *J. Assoc. Physic. India* 27:347-348.
- Harden RA, and Baetjer AM. 1978. Aplastic anemia following exposure to p-dichlorobenzene and naphthalene. *J. Occup. Med.* 20: 820-822.
- Harris J, Bond GP, and Niemeier RW. 1979. The effects of 2-nitropropane, naphthalene, and hexachlorobutadiene on fetal rat development. [Abstract]. *Toxicol. Appl. Pharmacol.* 48:A35.
- HSDB. 2006. Hazardous Substances Data Bank. Available online at <http://toxnet.nlm.nih.gov>
- Kurz JM. 1987. Naphthalene poisoning. Critical care nursing techniques. *Dimens. Crit. Care Nurs.* 6:264-270.
- Linick M. 1983. Illness associated with exposure to naphthalene in mothballs - Indiana. *MMWR* 32:34-35.
- Molloy EJ, Doctor BA, Reed MD, Walsh MC. 2004. Perinatal toxicity of domestic naphthalene exposure. *J Perinatol.* 24(12):792-793.
- Manchanda SS, and Sood SC. 1960. Accidental poisoning in children: with a case report of naphthalene poisoning. *Ind. J. Child Health* 9(2):113-119.
- Navarro H, Proce C, Marr M, and Myers C. 1991. Developmental toxicity evaluation of naphthalene administered by gavage to Sprague-Dawley rats on gestational days 6 through 15. Research Triangle Institute. Research Triangle Park, NC: National Toxicology Program.
- NTP. 1992. Toxicology and Carcinogenesis Studies of Naphthalene in B6C3F1 Mice. Technical Report Series No. 410. NIH Publication No. 92-3141.
- NTP. 2000. Toxicology and Carcinogenesis Studies of Naphthalene in F344/N Rats. Technical Report Series No. TR-500.
- OEHHA, 2000. Air Toxics Hot Spots Program Risk Assessment Guidelines Part III Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels, April 2000.
- OEHHA, 2005. Proposed Identification of Environmental Tobacco Smoke as a Toxic Air Contaminant Part B: Health Effects.

- OEHHA, 2001 Prioritization of Toxic Air Contaminants Under the Children's Environmental Health Protection Act. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, October, 2001.
- Phimister AJ, Lee MG, Morin D, Buckpitt AR, Plopper CG. 2004. Glutathione depletion is a major determinant of inhaled naphthalene respiratory toxicity and naphthalene metabolism in mice. *Toxicol Sci.* 82(1):268-278.
- Preuss R, Koch HM, Wilhelm M, Pischetsrieder M, Angerer J. 2004. Pilot study on the naphthalene exposure of German adults and children by means of urinary 1- and 2-naphthol levels. *Int J Hyg Environ Health.* 207(5):441-445.
- Rappaport SM, Waidyanatha S, Serdar B. 2004. Naphthalene and its biomarkers as measures of occupational exposure to polycyclic aromatic hydrocarbons. *J Environ Monit.* 6(5):413-4136.
- Sagunski H, Heger W. 2004. [Reference values for indoor room air: naphthalene.] *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz.* 47(7):705-712. [Article in German.]
- Shopp GM, White KL, and Hosapple M. 1984. Naphthalene toxicity in CD-1 mice: General toxicology and immunotoxicology. *Fundam. Appl. Toxicol.* 4:406-429.
- Siegel E, and Wason S. 1986. Mothball toxicity. *Pediatr. Clin. North Am.* 33:369-374.
- Sonnenfeld WJ, Zoller WH, and May WE. 1983. Dynamic coupled-column liquid chromatographic determination of ambient temperature vapor pressures of polynuclear aromatic hydrocarbons. *Anal. Chem.* 55(2):275-280.
- U.S.EPA. 1986a. U.S. Environmental Protection Agency. Developmental toxicity study in rabbits. PH 329-TX-001-85. 86-870000563. Office of Research and Development, Cincinnati, OH.
- U.S.EPA. 1986b. U.S. Environmental Protection Agency. Ninety day (sub-chronic) dermal toxicity study with naphthalene in albino rats. 65-870000565. Cincinnati, OH: Office of Research and Development.
- U.S.EPA. 1990. U.S. Environmental Protection Agency. Drinking Water Health Advisories for 15 Volatile Organic Chemicals. U.S. EPA/ODW. NTIS No. PB90-259821.
- U.S. EPA. 1994. U.S. Environmental Protection Agency Methods for Derivation of Inhalation Reference Concentrations and Application of Inhalation Dosimetry. EPA/600/8-90/066F. Office of Research and Development. Washington, DC: U.S.EPA.

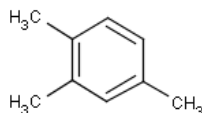
- U. S. EPA. 2000. U.S. Environmental Protection Agency. Integrated Risk Information System (IRIS). Naphthalene. Available on-line at <http://www.epa.gov/IRIS/subst/0436.htm>
- Valaes T, Doxiadis SA, and Fessas T. 1963. Acute hemolysis due to naphthalene inhalation. *J. Pediatr.* 63:904-915.
- van der Hoeve, J. 1906. [Chorioretinitis in humans from the effects of naphthalene] [in German]. *Arch. Augenheilkd.* 56:259-262. [reviewed in ATSDR, 1995].
- Waidyanatha S, Zheng Y, Serdar B, Rappaport SM. 2004. Albumin adducts of naphthalene metabolites as biomarkers of exposure to polycyclic aromatic hydrocarbons. *Cancer Epidemiol Biomarkers Prev.* 13(1):117-124.
- West JA, Williams KJ, Toskala E, Nishio SJ, Fleschner CA, Forman HJ, Buckpitt AR, Plopper CG. 2002. Induction of tolerance to naphthalene in Clara cells is dependent on a stable phenotypic adaptation favoring maintenance of the glutathione pool. *Am J Pathol.* 160(3):1115-1127. Erratum in: *Am J Pathol.* 2003 Aug;163(2):803.
- West JA, Van Winkle LS, Morin D, Fleschner CA, Forman HJ, Plopper CG. 2003. Repeated inhalation exposures to the bioactivated cytotoxicant naphthalene (NA) produce airway-specific Clara cell tolerance in mice. *Toxicol Sci.* 75(1):161-168.
- Willems BAT, Melnick RL, Kohn MC, Portier CJ. 2001. A Physiologically Based Pharmacokinetic Model for Inhalation and Intravenous Administration of naphthalene in rats and mice. *Toxicology and Applied Pharmacology*, 176(2):81-91.
- Wolf, O. 1978. Cancer of the larynx in naphthalene cleaner. *Z. Gesamte. Hyg.* 24(10):737-739.

FINAL TOXICITY SUMMARY FOR AN 8-HOUR AIR REL

1, 2, 4-TRIMETHYLBENZENE

(Pseudocumene; Asymmetrical trimethylbenzene)

CAS Registry Number: 95-63-6



I. Toxicity Summary

<i>8-Hour inhalation reference exposure level</i>	300 µg/m³ (60 ppb)
<i>Critical effect(s)</i>	Decreased neuromuscular function, decreased RBC count, and pulmonary lesions in rats
<i>Hazard index target(s)</i>	Nervous system, hematological system, respiratory system

II. Physical and Chemical Properties [HSDB (2005) except as noted]

<i>Description</i>	Clear, colorless liquid
<i>Molecular formula</i>	C ₆ H ₃ (CH ₃) ₃
<i>Molecular weight</i>	120.2 g/mol
<i>Density</i>	0.8761 g/cm ³ @ 20 °C (water = 1)
<i>Boiling point</i>	168.89 °C
<i>Melting point</i>	-43.8 °C
<i>Vapor pressure</i>	2.10 mm Hg @ 25 °C
<i>Odor threshold in air</i>	Distinctive aromatic odor; odor threshold unknown
<i>Solubility</i>	Miscible in most organic solvents; insoluble in water
<i>Conversion factor</i>	1 ppm = 4.92 mg/m ³

III. Major Indoor Uses, Sources and Quantified Exposures

1,2,4-Trimethylbenzene (1,2,4-TMB), or pseudocumene, is one of three isomeric forms of trimethylbenzene; the 1,2,3- isomer is called hemellitol, and the 1,3,5- isomer is called mesitylene. They are prepared from petroleum and coal tar and used as solvents for resins, gums, and nitrocellulose, and used as intermediates for other chemical compounds. Building materials and products used indoors that may emit 1,2,4-TMB

include floor/wall coverings, linoleum floor coverings, caulking compounds, vinyl coated wallpaper, jointing compounds, cement flagstone, paint thinners, floor varnishes, chipboard, wood stains, carpets and floor waxes (Tichenor and Mason, 1988; Van der Wal *et al.*, 1997; HSDB, 2005). Other sources of trimethylbenzenes that can contaminate indoor environments include motor vehicle fuel and emissions, and environmental tobacco smoke (Jarnberg *et al.*, 1996; Pankow *et al.*, 2004).

A number of workplace VOC emission studies have analyzed for 1,2,4-TMB or TMBs. The geometric mean concentration of 1,2,4-TMB in 12 California office buildings was $3.7 \mu\text{g}/\text{m}^3$ (range: $1.4\text{--}8.4 \mu\text{g}/\text{m}^3$) (Daisey *et al.*, 1994). Based on the known indoor and outdoor concentrations of benzene, assumed to be emitted only by motor vehicles, it was estimated that 85% of the indoor concentration of 1,2,4-TMB was contributed by motor vehicle emissions. Vehicles operating in a basement level parking garage were thought to be the major contributor of 1,2,4-TMB in upper levels of a new office building (Hodgson *et al.*, 1991). In other U.S. studies, 1,2,4-TMB was detected in most office buildings analyzed and had concentrations ranging from 0.3 to $25 \mu\text{g}/\text{m}^3$ (Girman *et al.*, 1986; Shields *et al.*, 1996). Indoor concentrations of 1,2,4-TMB have been measured as high as $398 \mu\text{g}/\text{m}^3$ in a photocopy center, due likely to a combination of emissions from an offset printing operation and lack of ventilation (Stefaniak *et al.*, 2000). Among four new relocatable classrooms in California, the average 1,2,4-TMB concentration measured over 8 weeks during school hours ranged from 0.4 to $0.9 \mu\text{g}/\text{m}^3$ (Hodgson *et al.*, 2004). The emissions originated from vinyl-covered fiberboard wall panels and sheet vinyl flooring.

In a Finnish population exposure study, indoor and outdoor exposures were determined for mixed trimethylbenzenes in a subgroup of up to 183 participants (Edwards *et al.*, 2001). Trimethylbenzenes were detected in 79% of workplace environments. Arithmetic mean concentrations of trimethylbenzenes were $6.3 \mu\text{g}/\text{m}^3$ ($\text{SD} = 13.8 \mu\text{g}/\text{m}^3$) in non-environmental tobacco smoke (ETS) exposed workplaces and $13.2 \mu\text{g}/\text{m}^3$ in ETS-exposed workplaces ($\text{SD} = 37.2 \mu\text{g}/\text{m}^3$), exhibiting a marginal association with ETS ($p = 0.068$ by Wilcoxon W test). Increased residential outdoor concentrations of trimethylbenzenes were associated with high traffic areas, but traffic volume did not have a significant effect on indoor workplace concentrations.

In chamber studies, an investigation of new building materials found that some samples of tire-derived, rubber-based resilient floorings emitted 1,2,4-TMB (IWMB, 2003). Modeled air concentrations for a typical office ranged from 73 to $320 \mu\text{g}/\text{m}^3$ 1,2,4-TMB based on 96-hour emission rates. In other chamber studies, three of 19 new samples of PVC-flooring materials emitted trimethylbenzenes, resulting in a modeled concentration as high as $130 \mu\text{g}/\text{m}^3$ four weeks following installation in a small room (Lundgren *et al.*, 1999). The median emission rate of trimethylbenzenes decreased by 67% between week 4 and 26 after manufacture.

IV. Effects of Human Exposure

No studies relating 1,2,4-TMB exposure to adverse health effects in humans were located in the literature. Exposure of 10 male volunteers to 2 or 25 ppm 1,2,4-TMB for 2 hours with light exercise (50 W) did not result in sensory irritation or CNS symptoms (Jarnberg *et al.*, 1996). However, ratings of odor were noted at both concentrations and had increased significantly from 2 to 25 ppm.

Toxicokinetic studies in humans indicated that inhalation exposures (1 to 30 ppm) to 1,2,4-TMB resulted in a respiratory uptake of 63-68% and extensive accumulation in adipose tissue (Jarnberg *et al.*, 1996; Kostrzewski *et al.*, 1997). 1,2,4-TMB has a moderately rapid excretion rate with a half-life of 4-6 hrs and 22% of the inhaled dose excreted in urine as dimethylhippuric acids within 24 hrs (Jarnberg *et al.*, 1996). The terminal half-life phase was 65 to 87 hrs for 2 hr exposures to 2 and 25 ppm 1,2,4-TMB, respectively, and reflects the washout time from fat tissue. Metabolic elimination of 1,2,4-TMB can be inhibited with co-exposure to other solvents (Jarnberg *et al.*, 1997). Based on the human toxicokinetic exposure data, Jarnberg and Johanson (1999) developed a PBPK model for 1,2,4-TMB and showed that daily 8-hour exposures (25 ppm, in this example) over a workweek will result in a gradual increase of 1,2,4-TMB and its metabolites in prior-to-shift blood samples. While precise 1,2,4-TMB concentrations in prior-to-shift blood samples were not provided, the graphed data shown suggests an approximate 3-4x increase in prior-to-shift blood levels by the end of the workweek. However, end-of-shift blood levels remained fairly constant during the week, reflecting same day exposure. Modeling of prior-to-shift blood levels the following Monday morning after the weekend noted that 1,2,4-TMB was still elevated relative to the previous Tuesday morning blood levels.

V. Effects of Animal Exposure

As in humans, 1,2,4-TMB in rats is well absorbed across the respiratory tract, rapidly distributes to organs including the brain, accumulates in the fat, and is metabolized primarily to dimethylbenzoic acids (Swiercz *et al.*, 2002). Zahlsen *et al.* (1990) observed a fat/blood and brain/blood distribution ratio of 63 and 2, respectively, in rats that inhaled 1,2,4-TMB. In humans, fat/blood and rapidly perfused tissues/blood (including brain) ratio estimates derived from toxicokinetic modeling were 125 and 5, respectively (Jarnberg and Johanson, 1999).

Neurotoxic and respiratory effects were assessed following 4-hour exposures to 250-2000 ppm 1,2,4-TMB (Korsak *et al.*, 1995; Korsak and Rydzynski, 1996). EC₅₀ values of 954 and 1155 ppm were observed in rats for the rotarod performance test (an index of normal neuromuscular function) and hot-plate test (measure of the level of analgesia), respectively. The concentration depressing the respiratory rate in mice to 50% (RD₅₀) in the first minute of exposure was 578 ppm (95% C.I. = 311-793 ppm).

A battery of behavioral tests was performed in male rats 14 to 54 days after 4-week inhalation exposure to 25, 100, or 250 ppm (6 hr/day, 5 days/week) 1,2,4-TMB

(Gralewicz *et al.*, 1997b). While exposure had no influence on general health status or cognitive tests, behavioral alterations were observed for the passive avoidance test (shorter step-down time from safe area after foot shock) and hot plate test (increased latency to paw-lick in response to heat after intermittent footshock) at 100 and 250 ppm. However, the behavioral effects at 250 ppm were not as severe as at 100 ppm. Increased locomotor activity was observed only at 100 ppm. These findings were supported in a similar 4-week exposure study with one dose level (100 ppm) (Gralewicz and Wiaderna, 2001). Taken together, these changes indicate a persistent decreased capacity to control locomotor response, especially in a stress-inducing environment. In a separate study, the same exposure regimen of 25, 100 and 250 ppm (6 hr/day, 5 days/week) for 4 weeks resulted in retardation of the age-related increase of spontaneous cortical spike-wave discharges from the brains of rats exposed at the two highest concentrations (Gralewicz *et al.*, 1997a). The toxicological consequence of this effect was unclear, although it was theorized that it may be related to an adaptation to the CNS-depressing effect of 1,2,4-TMB.

Behavioral tests conducted in rats during and following 13-week intermittent exposures to 25, 100, or 250 ppm 1,2,4-TMB showed a concentration-dependent increase in the number of failures on the rotarod test that was significant at 250 ppm (Korsak and Rydzynski, 1996). Significant disturbances were recorded at 8 and 13 weeks, but not 4 weeks, suggesting a cumulative effect with continued exposure. The hot-plate test conducted immediately after exposure resulted in an increased latency of the paw-lick response (i.e., decreased sensitivity to pain) that was concentration-dependent and significantly different from control values at 100 and 250 ppm. Both behavioural tests conducted again two weeks after termination of exposure observed no statistically significant difference from controls, but responses had not completely recovered to control levels.

In another 13-week study, rats exposed to 129, 492, or 1207 mg/m³ (about 25, 100, and 250 ppm, respectively) 1,2,4-TMB for 6 hr/day, 5 days/week showed pathological effects to the pulmonary and hematological systems (Korsak *et al.*, 2000). Lower respiratory tract inflammation included concentration-dependent increases in interstitial lymphocytic infiltrations in females that were statistically significant at 250 ppm, and increased alveolar macrophages in males that were statistically significantly increased also at 250 ppm. Cumulative pulmonary lesion scores showed a concentration-dependent effect in both genders, with a statistically significant difference from controls in 100 ppm males. Dose-dependent decreases in red blood cells and increases in white blood cells occurred in male rats, which was statistically significant at the highest concentration and possibly related to the pulmonary inflammation. Sorbitol dehydrogenase activity was increased at all treatment levels in males, suggesting liver damage. However, microscopic examination of the liver was unremarkable.

A 13-week study in male rats exposed to 25, 100, or 250 ppm 1,2,4-TMB (6 hr/day, 5 days/week) investigated indices of respiratory effects in bronchoalveolar lavage (BAL) fluid (Korsak *et al.*, 1997). Total cells and macrophages in BAL fluid were increased starting at 25 and 100 ppm, respectively. At 25 ppm, total protein, lactate dehydrogenase

activity and acid phosphatase activity were increased, and mucoprotein levels decreased, but lack of effects at 250 ppm and lack of strong trends make these results difficult to interpret, particularly when lung histopathology by Korsak *et al.* (2000) observed no effects at 25 ppm. It was suggested that the lack of a concentration-dependent effect for the BAL indices might be due to some form of adaptation to respiratory irritation at the higher concentrations (Korsak *et al.*, 1997).

In a developmental study, pregnant rats were exposed to 100, 300, 600, or 900 ppm 1,2,4-TMB for 6 hr/day on gestational days 6-20 (Saillenfait *et al.*, 2005). Maternal toxicity consisted of decreased body weight gain and decreased food consumption at the two highest concentrations by the 8th day of exposure. No other signs of maternal toxicity were noted in any treatment group. Embryo lethality and teratogenicity was not observed in the fetal offspring. However, a dose-dependent decrease in body weights occurred that was significantly different from controls at 600 and 900 ppm (5% and 11-12% reductions, respectively), demonstrating that 1,2,4-TMB adversely affected fetal growth only at maternally toxic concentrations.

The Benchmark Concentrations (BMCs) and No Observable Adverse Effect Levels (NOAELs) for the principal toxic endpoints in the 13-week and developmental exposure studies are listed in Table 1. The BMC₀₅ is the lower 95% confidence limit on the concentration producing a 5% response and is considered to be an improved approximation of the NOAEL in estimating a concentration associated with a low level of risk. The BMC modeling software was obtained from U.S. EPA (2003). For each endpoint, the BMC₀₅ was derived from the model that provided the best visual and statistical fit to the data. Following U.S. EPA guidelines, the model with the lowest AIC (Akaike information criterion) was chosen in instances where model fits were similar among more than one acceptable model.

Table 1: BMC₀₅'s and NOAEL's for principal toxic endpoints resulting from exposure to 1,2,4-TMB in rats.

Endpoint	BMC ₀₅ (ppm)	NOAEL (ppm)
CNS Effects (Korsak and Rydzynski, 1996)		
Rotarod test	36 [†]	100
Hot plate test	NA ^{††}	25
Respiratory Effects (Korsak <i>et al.</i> , 2000)		
Cumulative pulmonary lesion score (males)	NA	25
Interstitial lymphocytic infiltrations (females)	NA	100
Increased alveolar macrophages (males)	NA	100
Hematological Effects (Korsak <i>et al.</i> , 2000)		
Decreased red blood cell count	38*	25
Increased white blood cell count	NA	100
Developmental Effects (Saillenfait <i>et al.</i> , 2005)		
Reduced maternal corrected body weight	557**	600
Reduced maternal food intake	121**	300
Reduced fetal body weight	496**	300

[†] Based on the probit model for a dichotomous data set.

^{††} Not appropriate. A BMC determination could not be performed with the type of data available, or an acceptable model fit could not be generated for the data.

* Based on the linear model for a continuous data set.

** Based on the polynomial model for a continuous data set.

VI. Derivation of Indoor 8-Hour Reference Exposure Level

OEHHA is currently re-evaluating the methods for REL development, primarily to ensure adequate protection of infants and children. Thus, RELs developed with the current methodology may be revisited in the future.

<i>Study</i>	Korsak and Rydzynski (1996); Korsak et al., 2000
<i>Study population</i>	Male and female Wistar rats
<i>Exposure method</i>	Discontinuous whole-body inhalation exposure to 0, 25, 100, and 250 ppm
<i>Critical effects</i>	Decreased neuromuscular function and red blood cell count; pulmonary lesions
<i>LOAEL</i>	100 ppm
<i>NOAEL</i>	25 ppm
<i>Exposure continuity</i>	6 hr/day, 5 days/week
<i>Average experimental exposure</i>	19 ppm (25 ppm x 6/8 x 5/5)
<i>Human equivalent concentration (HEC)</i>	19 ppm (RGDR = 1 based on inhalation uptake estimates for rat > human)
<i>Exposure duration</i>	13 weeks
<i>LOAEL uncertainty factor</i>	1
<i>Subchronic uncertainty factor</i>	3 (8-12% of estimated lifetime)
<i>Interspecies uncertainty factor</i>	3 (for pharmacodynamic uncertainties)
<i>Intraspecies uncertainty factor</i>	30
<i>Cumulative uncertainty factor</i>	300
<i>Indoor Air Reference exposure level</i>	0.06 ppm (0.3 mg/m ³ , 300 µg/m ³ , 60 ppb)

Although new building materials and products show a decline in off-gas emissions of 1,2,4-TMB over 6 months, the potential for ongoing infiltration of 1,2,4-TMB into buildings from combustion engine sources suggests ubiquitous low-level exposure to 1,2,4-TMB can occur. The cumulative CNS effects in rats with increasing exposure duration and the observation of accumulation of 1,2,4-TMB in humans with daily intermittent exposure supports the use of chronic/subchronic exposure data for developing an 8-hr REL. Human toxicity data is lacking for REL development, requiring the use of the subchronic rodent toxicity studies.

The series of 4-week and 13-week 1,2,4-TMB exposure studies at 25, 100, and 250 ppm generally show that 25 ppm and 100 ppm are the NOAEL and LOAEL, respectively, for CNS and respiratory effects in rats (Korsak and Rydzynski, 1996; Gralewicz *et al.*, 1997b; Korsak *et al.*, 1997; Korsak *et al.*, 2000; Gralewicz and Wiaderna, 2001). The 13-week CNS (rotarod test) and hematology (RBC count) findings provided satisfactory data for BMC determination (Table 1). Other data that did not succeed for a BMC determination, but provided information for a NOAEL/LOAEL approach, included the pulmonary histopathology data (cumulative histopathology score in males) and other CNS data (latency to paw-lick response on hot plate after intermittent foot shock). The BMC₀₅'s and NOAELs for these effects were similar: BMC₀₅ = 36 and 38 ppm for

rotarod test and decreased RBCs, respectively, NOAEL = 25 ppm for respiratory effects and latency to paw-lick response.

Although BMC₀₅s could not be determined for the respiratory effects and hot plate test findings, the 8-hour REL was based on their NOAELs of 25 ppm. Given that BMC₀₅s are equivalent to a NOAEL, the lowest NOAEL/BMC₀₅ was chosen as the basis of the REL. The average experimental exposure was adjusted to 19 ppm for an eight-hour exposure, five days/week. For the HEC calculation, an RGDR = 1 was used for both systemic and respiratory endpoint effects based on comparisons of 1,2,4-TMB inhalation uptake estimates for rats and humans. Human data are available for the 1,2,4-TMB blood:air partition coefficient, but similar data for rats could not be located in the literature. Thus, interspecies pharmacokinetic comparisons of maximum blood levels and area-under-the-curve (AUC) could not be estimated. . Dahl *et al.* (1988) calculated an average uptake of 13.6 nmol/kg/min/ppm in rats inhaling 100 ppm 1,2,4-TMB for about 80 min. For humans, Jarnberg *et al.* (1998) provided a net respiratory uptake of 1.52 mmol 1,2,4-TMB in volunteers inhaling 25 ppm 1,2,4-TMB for 120 min, and weighing an average of 77 kg. The calculated human inhalation uptake was 6.6 nmol/kg/min/ppm. An RGDR = 1 is used if the rat 1,2,4-TMB uptake is greater than human 1,2,4-TMB uptake.

For potential pharmacodynamic differences not accounted for by the HEC approach, an interspecies UF = 3.16 was applied. Considering the ubiquitous nature of exposure and evidence for cumulative CNS effects with increasing exposure duration, a subchronic UF = 3.16 was applied to account less than lifetime exposure in the primary study. In addition, an intraspecies default UF = 30 was used for protection of children. The intraspecies default UF = 30 applies for chemicals that have systemic effects, particularly when the CNS is a critical endpoint and no information is available on the susceptibility of the developing brain in children. The adjusted BMC₀₅ is divided by the cumulative UF = 300, resulting in the 8-hour REL of 60 ppb (300 µg/m³).

A comparison to the 8-hour REL can be performed using the maternal data from Saillenfait *et al.* (2005) in which decreased maternal food consumption in pregnant female rats was observed during and following 6-hour daily exposures to 1,2,4-TMB during pregnancy (gestational days 6-20). This maternal parameter was one of the most sensitive endpoints in the developmental study, and reflected the reduction in maternal body weight gain. A BMC₀₅ of 121 ppm was estimated, based on the U.S. EPA (2003) polynomial model for a continuous data set. Correction for a daily 8-hr, 5 days/week exposure duration results in an average experimental exposure of 91 ppm. A total UF of 1000 (3.16 for interspecies, 30 for intraspecies, 10 for subchronic) results in an 8-hour REL of 90 ppb (400 µg/m³).

VII. Evidence for Differential Toxicity in Children

No human inhalation studies were found that addressed differential sensitivity in children relative to adults with exposure to 1,2,4-TMB. Although a comprehensive developmental study in rats did not find any teratogenic effects or increased sensitivity in newborns

relative to maternal sensitivity, no pre- or post-natal neurodevelopmental studies have been performed. Neurobehavioral and neuromuscular effects are critical endpoints in adult animals with exposure to 1,2,4-TMB, and the developing brain may be more susceptible to exposure. Additionally, a multi-generation 1,2,4-TMB exposure study has not been performed.

VIII. Data Strengths and Limitations for Development of the REL

Significant strengths for the REL include independent animal studies demonstrating toxic effects at similar concentrations, and pharmacokinetic data in both animals and humans. Limitations include the lack of a human dose-response study that include both a NOAEL and a LOAEL, lack of an animal chronic inhalation study, and the weak database for reproductive/developmental studies (i.e., only one animal species examined; no multi-generation studies).

IX. Executive Summary

1,2,4-trimethylbenzene (1,2,4-TMB) is a common chemical found in solvents and gasoline. Solvents that contain 1,2,4-TMB will typically have a gasoline or oil-like odor. Solvent-based adhesives used in building materials may emit 1,2,4-TMB. Solvent-based surface coatings such as paint, paint thinners, and floor varnishes may also emit 1,2,4-TMB, as well as any other consumer products that contain organic solvents.

A Indoor Reference Exposure Level (IREL) is a “safe” air concentration of a chemical at or below which no adverse effects are anticipated for repeated daily 8-hour exposures. The 8-hour IREL for 1,2,4-TMB is based on the adverse health effect reported in the medical and toxicological literature that occurs at the lowest air concentration of the chemical. It includes a margin of safety to protect the most sensitive individuals in the diverse general population, and to account for scientific uncertainties. Exposure to 1,2,4-TMB at concentrations above the IREL does not necessarily mean that health effects will occur because of the margin of safety. However, the likelihood of health effects increases as the exposure concentration increases above the IREL concentration.

The health effects that occur with 1,2,4-TMB exposure in animal experiments include loss of balance and lack of muscle control, decreased numbers of red blood cells, and lung inflammation. No toxicological information could be found regarding the effects of daily exposure to 1,2,4-TMB in humans. The 8-hr REL is based on the highest concentration that did not result in these adverse effects in rats that occur at yet higher concentrations, and is known as the No-Observed-Adverse-Effect-Level (NOAEL), with a margin of safety.

X. References

Dahl, A. R., Damon, E. G., Mauderly, J. L., Rothenberg, S. J., Seiler, F. A., and McClellan, R. O. (1988). Uptake of 19 hydrocarbon vapors inhaled by F344 rats. *Fundam Appl Toxicol* **10**, 262-269.

- Daisey, J. M., Hadgson, A. T., Fisk, W. J., Mendell, M. J., and Ten Brinke, J. (1994). Volatile organic compounds in twelve California office buildings: Classes, concentrations and sources. *Atmospheric Environment* **28**, 3557-3562.
- Edwards, R. D., Jurvelin, J., Saarela, K., and Jantunen, M. (2001). VOC concentrations measured in personal samples and residential indoor, outdoor and workplace microenvironments in EXPOLIS-Helsinki, Finland. *Atmospheric Environment* **35**, 4531-4543.
- Girman, J. R., Hodgson, A. T., and Newton, A. S. (1986). Emissions of volatile organic compounds from adhesives with indoor applications. *Environment International* **12**, 317-321.
- Gralewicz, S., and Wiaderna, D. (2001). Behavioral effects following subacute inhalation exposure to m-xylene or trimethylbenzene in the rat: a comparative study. *Neurotoxicology* **22**, 79-89.
- Gralewicz, S., Wiaderna, D., and Tomas, T. (1997a). Retardation of the age-related increase in spontaneous cortical spike-wave discharges (SWD) in rats after a 28-day inhalation exposure to an industrial solvent, pseudocumene (1,2,4-trimethylbenzene). *International Journal of Occupational Medicine and Environmental Health* **10**, 213-222.
- Gralewicz, S., Wiaderna, D., Tomas, T., and Rydzynski, K. (1997b). Behavioral changes following 4-week inhalation exposure to pseudocumene (1,2,4-trimethylbenzene) in the rat. *Neurotoxicology and Teratology* **19**, 327-333.
- Hodgson, A. T., Daisey, J. M., and Grot, R. A. (1991). Sources and source strengths of volatile organic compounds in a new office building. *J. Air Waste Manage. Assoc.* **41**, 1461-1468.
- Hodgson, A. T., Shendell, D. G., Fisk, W. J., and Apte, M. G. (2004). Comparison of predicted and derived measures of volatile organic compounds inside four new relocatable classrooms. *Indoor Air* **14 Suppl 8**, 135-144.
- HSDB (2005). Hazardous Substances Data Bank. National Library of Medicine, Bethesda, MD. Available at: <http://toxnet.nlm.nih.gov>.
- IWMB (2003). Integrated Waste Management Board. Building Material Emissions Study. Sacramento, CA. Available at: www.ciwmb.ca.gov/Publications.
- Jarnberg, J., and Johanson, G. (1999). Physiologically based modeling of 1,2,4-trimethylbenzene inhalation toxicokinetics. *Toxicol Appl Pharmacol* **155**, 203-214.
- Jarnberg, J., Johanson, G., and Lof, A. (1996). Toxicokinetics of inhaled trimethylbenzenes in man. *Toxicol Appl Pharmacol* **140**, 281-288.
- Jarnberg, J., Johanson, G., Lof, A., and Stahlbom, B. (1997). Inhalation toxicokinetics of 1,2,4-trimethylbenzene in volunteers: comparison between exposure to white spirit and 1,2,4-trimethylbenzene alone. *Sci Total Environ* **199**, 65-71.
- Jarnberg, J., Johanson, G., Lof, A., and Stahlbom, B. (1998). Toxicokinetics of 1,2,4-trimethylbenzene in humans exposed to vapors of white spirit: comparison with exposure to 1,2,4-trimethylbenzene alone. *Arch Toxicol* **72**, 483-491.
- Korsak, Z., and Rydzynski, K. (1996). Neurotoxic effects of acute and subchronic inhalation exposure to trimethylbenzene isomers (pseudocumene, mesitylene, hemimellitene) in rats. *Int J Occup Med Environ Health* **9**, 341-349.

- Korsak, Z., Rydzynski, K., and Jajte, J. (1997). Respiratory irritative effects of trimethylbenzenes: an experimental animal study. *Int J Occup Med Environ Health* **10**, 303-311.
- Korsak, Z., Stetkiewicz, J., Majcherek, W., Stetkiewicz, I., Jajte, J., and Rydzynski, K. (2000). Sub-chronic inhalation toxicity of 1,2,4-trimethylbenzene (pseudocumene) in rats. *Int J Occup Med Environ Health* **13**, 155-164.
- Korsak, Z., Swiercz, R., and Rydzynski, K. (1995). Toxic effects of acute inhalation exposure to 1,2,4-trimethylbenzene (pseudocumene) in experimental animals. *Int J Occup Med Environ Health* **8**, 331-337.
- Kostrzewski, P., Wiaderna-Brycht, A., and Czerski, B. (1997). Biological monitoring of experimental human exposure to trimethylbenzene. *Sci Total Environ* **199**, 73-81.
- Lundgren, B., Jonsson, B., and Ek-Olausson, B. (1999). Materials emission of chemicals-PVC flooring materials. *Indoor Air* **9**, 202-208.
- Pankow, J. F., Luo, W., Tavakoli, A. D., Chen, C., and Isabelle, L. M. (2004). Delivery levels and behavior of 1,3-butadiene, acrylonitrile, benzene, and other toxic volatile organic compounds in mainstream tobacco smoke from two brands of commercial cigarettes. *Chem Res Toxicol* **17**, 805-813.
- Saillenfait, A. M., Gallissot, F., Sabate, J. P., and Morel, G. (2005). Developmental toxicity of two trimethylbenzene isomers, mesitylene and pseudocumene, in rats following inhalation exposure. *Food Chem Toxicol* **43**, 1055-1063.
- Shields, H. C., Fleischer, D. M., and Weschler, C. J. (1996). Comparisons among VOCs measured in three types of U.S. commercial buildings with different occupant densities. *Indoor Air* **6**, 2-17.
- Stefaniak, A. B., Breyse, P. N., Murray, M. P., Rooney, B. C., and Schaefer, J. (2000). An evaluation of employee exposure to volatile organic compounds in three photocopy centers. *Environ Res* **83**, 162-173.
- Swiercz, R., Rydzynski, K., Wasowicz, W., Majcherek, W., and Wesolowski, W. (2002). Toxicokinetics and metabolism of pseudocumene (1,2,4-trimethylbenzene) after inhalation exposure in rats. *Int J Occup Med Environ Health* **15**, 37-42.
- Tichenor, B. A., and Mason, M. A. (1988). Organic emissions from consumer products and building materials to the indoor environment. *JAPCA* **38**, 264-268.
- USEPA (2003). Benchmark Dose Software, National Center for Environmental Assessment. Online at: <http://cfpub2.epa.gov/ncea/cfm/recordisplay.cfm?deid=20167>.
- Van der Wal, J. F., Hoogeveen, A. W., and Wouda, P. (1997). The influence of temperature on the emission of volatile organic compounds from PVC flooring, carpet, and paint. *Indoor Air* **7**, 215-221.
- Zahlsen, K., Nilsen, A. M., Eide, I., and Nilsen, O. G. (1990). Accumulation and distribution of aliphatic (n-nonane), aromatic (1,2,4-trimethylbenzene) and naphthenic (1,2,4-trimethylcyclohexane) hydrocarbons in the rat after repeated inhalation. *Pharmacology & Toxicology* **67**, 436-440.

